JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA

FOR THE PROMOTION OF THE MECHANIC ARTS

VOL. CLXI, No. 4 81ST YEAR APRIL, 1906

The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the *Journal.*

THE FRANKLIN INSTITUTE.

Franklin as a Man of Science and an Inventor.*

[An address delivered by Dr. Edwin J. Houston, Emeritus Professor of Physics, Franklin Institute, on February 21, 1906, on the occasion of the 200th anniversary of the birth of Benjamin Franklin.]

[In this review of Benjamin Franklin's activity in the domain of the Physical Sciences, the author presents a compendium of authoritative data on all the many aspects of his subject and elucidates the data by a comprehensive and critical analysis of its various features. Dr. Houston's work deals with the whole range of Franklin's experiments and inventions and especially with those which so signally opened the way for the development of modern electrical technology.—THE EDITOR.]

It gives me sincere pleasure, ladies and gentlemen, on returning, after an absence of so many years, to the lecture room of the Franklin Institute, where I spent so many hours of my earlier life, to be assigned the agreeable task of addressing you on Benjamin Franklin as a Man of Science and an Inventor.

*Copyrighted by Edwin J. Houston, 1906.

One can scarcely appreciate the magnitude of the task assigned me by the title of this address.

As you all know, there stands in front of the U. S. Post Office Building, Ninth and Chestnut Streets, in this City, a statue of Benjamin Franklin. The pedestal contains the following inscription:

BENJAMIN FRANKLIN
1706—1790
Venerated
For Benevolence
Admired for Talents
Esteemed for Patriotism
Beloved for
Philanthropy

It is to Benjamin Franklin, who may properly be regarded as the most distinguished man of science that this country has ever produced, that I desire to call your attention.

Franklin was a many-sided man. I know of no living man I can at all compare with Benjamin Franklin, unless it is that 20th Century wonder, Thomas Edison. The two men are alike in many respects. Benjamin Franklin, a utilitarian, an apostle of thrift, a self-educated man. Thomas Edison, eminently utilitarian, as well as self-educated. Perhaps it may suffice if I show a single respect in which Franklin and Edison agree. If you will take the trouble to look even carelessly over the ten volumes on "The Works of Franklin," by Jared Sparks, or over the still more recent volumes of Prof. Smyth, of the High School, on "Benjamin Franklin," you will be able to gain some idea of the many-sidedness of Franklin, as well as the wide intellectual field he occupied. Perhaps this alliterative statement may aid you, since it briefly describes the varied powers of the man: Benjamin Franklin: Printer; Philosopher; Patriot; Philanthropist; Plenipotentiary; Postmaster; Politician in the purest and best sense of the word. or this simple statement: Benjamin Franklin: Writer; Physicist; Inventor; Statesman; and Man of Affairs.

As we contemplate the varied work of the man, we are apt to inquire: What single quality permitted this wonderful and

varied activity? It is not difficult to answer this question. Benjamin Franklin was a man who thoroughly appreciated the value of time, and who always made the most of the time he had at his disposal.

It is unnecessary for me to attempt to point out the many-sided character of Edison, since, as he lives in your time, you can hardly fail to be generally conversant with his work.

While it is far from my intention to weary you to-night with any extended dissertation respecting Franklin's economic philosophy as set forth in "Poor Richard's Almanac," yet I believe we can obtain no little insight into the cause for his success if you permit me to read a few quotations from "Poor Richard" respecting the husbanding of time:

"But dost thou love Life? Then do not squander time; for that is the stuff life is made of. How much more than is necessary do we spend in sleep!"

"The sleeping fox catches no poultry."

"There will be sleeping enough in the grave."

"If time be of all things the most precious, wasting time must be the greater prodigality."

"Lost time is never found again, and what we call time enough, always proves too little."

"He that riseth late, must trot all day, and shall scarce overtake his business at night."

"One to-day is worth two to-morrows."

"Never leave that until to-morrow which you can do to-day."

Methinks I hear some one of you say: "Must a man afford himself no leisure?" I will tell you, my friend, what "Poor Richard" says: "Employ thy time well if thou meanest to gain leisure; and since thou art not sure of a minute, throw not away an hour."

Thomas Edison holds to similar views. When once asked as to the principal inspiration that led to the wonderful results that he has achieved in applied physical science, he remarked: "It is not inspiration, but perspiration." Edison, too, holds similar views as to the loss of time that results from too much sleeping. It is not unusual, during the progress of an exacting investigation, that several consecutive days pass without his going to bed.

I warn you beforehand that, owing to the great scope of Franklin's work, covering, as it does, the fields of electricity, geographical physics, applied physics, as well as in other direc-

tions, it is only possible for me to very briefly indicate but a small portion of this work.

Franklin's first interest in the subject of electricity appears to have been excited in 1746, during a lecture on Electricity, delivered in Boston by a Dr. Spence. Franklin was, therefore, about forty years old when he first began the study of electricity.

As some of you may know, Franklin had formed a literary club, called the Junto, consisting of a few kindred spirits. This club had gathered together the few books they owned, and placed them in the meeting room at their club-house, where they used them in common. But in those days books were expensive, and were, moreover, ponderous, and not well suited for circulation; so that their library was not only small, but it was unsuited for circulation. In order to overcome these difficulties, Franklin conceived the idea of establishing a circulating library, and organized a regular association or company for this purpose. This company afterward became the great Library Company of Philadelphia.

At the Junto, essays, prepared by the club members, were read, and discussions held on the papers. On some occasions, simple experiments were performed for the purpose of illustrating the subject under discussion. Consequently when Franklin received from his friend, Peter Collinson, of London, a simple device in the form of an electrical tube, for the production of electricity by friction, not only were many experiments inaugurated before the Junto, but an extended series of investigations were made by Franklin, that resulted in obtaining for him a world-wide reputation as an experimental philosopher.

The apparatus employed by Franklin was not only limited in extent, but was of an exceedingly crude type. It is not, however, the apparatus that is of the greatest significance in the case of an experimental philosopher, but the type of brain power that directs its use, and then sits in deliberate judgment as to the most probable causes of the phenomena that have been obtained by its use.

It will be impossible to attempt any detailed description of the numerous experimental investigations made by this pro-

found philosopher. We must content ourselves with a brief discussion of only some of the more important of them.

Practically, Franklin began his study of electricity by studying the power of points. He communicated his observations on this matter in a letter to Collinson, dated July 11, 1747. This was the second letter sent to Collinson after the receipt of the electric tube. In a former letter, dated March 28, 1747, in which he acknowledged the receipt of the tube, Franklin refers to the great interest that he took in electric experiments. In his letter he says:

"For my own part, I never was before engaged in any study that so totally engrossed my attention and my time as this has lately done, for, what with making experiments when I can be alone, and repeating them to my Friends and Acquaintances, who, from the novelty of the thing, come continually in crowds to see them, I have, during some months past, had little leisure for anything else."

The second letter of Franklin to Collinson, above referred to, contains so much interesting matter that I feel warranted in having parts of it printed in full:

July 11, 1747.

"SIR:

"In my last, I informed you that, in pursuing our electrical enquiries, we had observed some particular Phaenomena, which we looked upon to be new, and of which I promised to give you some account, though I apprehended they might possibly not be new to you, as so many hands are daily employed in electrical experiments on your side of the water, some or other of which would probably hit on the same observations.

"The first is the wonderful effect of pointed bodies, both in *drawing off and throwing off* the electrical fire. For example,

(a) "Place an iron shot of three or four inches diameter on the mouth of a clean dry glass bottle. By a fine, silken thread from the ceiling, right over the mouth of the bottle, suspend a small cork-ball, about the bigness of a marble; the thread of such a length, as that the cork-ball may rest against the side of the shot. Electrify the shot, and the ball will be repelled to the distance of four or five inches, more or less, according to the quantity of electricity. When in this state, if you present to the shot the point of a long slender sharp bodkin, at six or eight inches distance, the repellency is instantly destroyed, and the cork flies to the shot. A blunt body must be brought within an inch, and draw a spark, to produce the same effect. (b) To prove that the electrical fire is *drawn off* by the point, if you take the blade of the bodkin out of the wooden handle, and fix it in a stick of sealing-wax, and then present it at the distance aforesaid, or if you bring it very

near, no such effect follows; but sliding one finger along the wax till you touch the blade, and the ball flies to the shot immediately. —— (c) If you present the point in the dark, you will see, sometimes at a foot distance, and more, a light gather upon it, like that of a fire-fly, or glow-worm; the less sharp the point, the nearer you must bring it to observe the light; and at whatever distance you see the light, you may draw off the electrical fire, and destroy the repellency. —— If a cork-ball so suspended be repelled by the tube, and a point be presented quick to it, tho' at a considerable distance, 'tis surprising to see how suddenly it flies back to the tube. Points of wood will do near as well as those of iron, provided the wood is not dry; for perfectly dry wood will no more conduct electricity than sealing-wax.

(d) "To show that points will *throw off* as well as *draw off* the electrical fire, lay a long, sharp needle upon the shot, and you cannot electrise the shot, so as to make it repel the cork-ball. —— Or fix a needle to the end of a suspended gun-barrel, or iron rod, so as to point beyond it like a little bayonet; and while it remains there, the gun-barrel, or rod, cannot by applying the tube to the other end be electrised so as to give a spark, the fire continually running out silently at the point. In the dark you may see it make the same appearace as it does in the case before mentioned.

(e) "The repellency between the cork ball and the shot is likewise destroyed. 1. By sifting fine sand on it; this does it gradually. 2. By breathing on it. 3. By making a smoke about it from burning wood. 4. By candle light, even though the candle is at a foot distance: these do it suddenly. —— The light of a bright coal from a wood fire; and the light from a red-hot iron do it likewise; but not at so great a distance. Smoke from dry rosin dropped on hot iron, does not destroy the repellency; but is attracted by both shot and cork-ball, forming proportionable atmospheres around them, making them look beautifully, somewhat like some of the figures in *Burnet's* or *Whiston's* theory of the earth.

"N. B.—This experiment should be made in a closet, where the air is very still, or it will be apt to fail.

"The light of the sun thrown strongly on both cork and shot by a looking glass for a long time together, does not impair the repellency in the least. This difference between fire-light and sun-light is another thing that seems new and extraordianry to us."

(a) Note here the simplicity of the apparatus employed. An iron shot, three or four inches in diameter, is insulated by being placed on a clean dry glass bottle; a small cork ball about the size of a boy's marble, suspended by a silk thread from the ceiling of the room, so that it rests against the side of the iron shot, is employed in order to indicate whether the shot is electrified or not, since the apparatus is capable of acting as a simple form of electroscope. Under these conditions, on the electrification of the shot, the cork is instantly repelled a distance of three

or four inches. In order to see the effects produced by the approaching of metallic bodies, *i. e.*, if bodies that possess the power of rapidly conducting electricity, Franklin brings the point of a long, slender, sharp bodkin to a distance of from six to eight inches from the shot. The effect is marked. The shot almost instantly loses its charge, as is indicated from the fact that it no longer repels the cork, which now falls until it touches the shot.

Does this discharge of the electrified shot result only from the fact that it is formed of conducting material, or is it also, and possibly mainly, determined by its shape. In order to settle this question, the same experiment is repeated. Now, however, a blunt metallic rod, instead of a sharp piece of pointed metal, is approached to the shot. No result is produced until the distance is sufficiently decreased to permit a spark to pass between the electrified shot and the blunt body. Clearly, then, the shape of the approaching body, *i. e.*, its pointed condition, is also an important determining factor.

(b) The same experiment is repeated, except, however, that a blunt instead of a sharp metallic body is approached to the cork. No effect is produced, until the distance is so short that a spark passes between the shot and the blunt body. Clearly, then, the shape of the approached body, *i. e.*, its pointed condition, is an important determining factor. On the approach of the blunt body, the electrified shot loses its electricity by an apparently single discharge, that is attended by a spark and a crackling sound. What is the difference in the character of this discharge and that which occurs on the approach of the pointed conductor? Does not the electricity continually pass off from the point in small quantities, and thus reach the ground?

In order to determine this question, Franklin contrives a charming experiment which convinces him that the electricity is drawn off by the point, or, as he calls it, in the form of electrical fire. He removes the blade of the bodkin from the wooden handle, which is but a poor insulator, and replaces it with a stick of sealing wax. Then, holding the bodkin by the sealing wax, he brings it as before within six or eight inches from the shot, or even nearer, without any effect following. Here the conditions are the same as before, except

that the sealing wax prevents the establishment of a conducting path to the ground. In order to convince himself that this result was due to the inability of the electric charge to pass along the bodkin to the wax support, and thus through his body to the ground, he slides one finger along the wax until the blade is touched, when instantly, a conducting path thus being established to the earth, a discharge of the shot and repulsion of the ball instantly ceases, the ball falling to the shot.

(c) Franklin repeats these experiments in the dark, and notes that a faint light can be observed as gathering on the point employed, somewhat resembling the light emitted by a fire-fly or glow-worm. He calls attention to the fact that the less sharp the point, the nearer it must be brought to the ball to be able to observe the light.

(d) But what effect would be produced if the charged body is itself pointed? To determine this, a long, sharp needle is laid on the shot. Under these conditions it is impossible to electrify the shot so as to repel the cork ball; for it parts with its charge as soon as it is received. Franklin gives to his friend, Mr. Thomas Hopkinson, the credit for first making this observation. Particular attention is called to Franklin's ingenious experiment of discharging the electrified shot by means of the smoke obtained from burning wood, or from the emanations given out by a lighted candle.

As intimated in Franklin's first letter to Collinson, these experiments, besides being tried before the Junto, were repeated to select audiences of friends and acquaintances. It is quite possible, by a careful reading of the latter part of Franklin's second letter to Collinson, to review some of the curious experiments that this ingenious man tried before these audiences. I will enumerate a few of these experiments, without any particular reference to the order in which Franklin described them:

(1) A lighted candle, when just blown out, is relighted by causing a spark to pass through the smoke between the wire and the snuffers. Here was first produced, although in a somewhat different manner, the well-known modern method of the electric ignition of gas lights by causing the spark of a spark-coil to pass through the jet of gas as it is issuing from a gas burner.

(2) Artificial lighting (and bear in mind this was in the year 1747, before it was actually known that the lightning flash is identical with an electric discharge) was produced by a wire carrying the current over a china plate decorated with gilt flowers; or similarly, by applying the wire to the gilt frames of looking-glasses. "We represent lightning," says Franklin, "by passing the wire in the dark over a china plate that has gilt flowers, etc."

(3) Place a person on a cake of wax (Franklin's simple form of insulating stool). Cause him to hold the electrified bottle in his hand, touching only the outer coating of the bottle. Then touch the wire with your finger, and bring it near his hand or face, when sparks are produced at each approach. Franklin explains this result in accordance with the single-fluid theory, as follows: By taking the spark from the wire, the electricity inside the bottle is decreased. The outside of the bottle then draws electricity from the person holding it, leaving him in the negative state; thus, when his hand or face is touched, an equal quantity is restored to him by the person touching.

(4) A small piece of burnt cork, so as to resemble a spider, is provided with legs of linen thread, and weighted with a grain or two of lead placed in the body. The counterfeit spider is hung over a table, on which an upright wire is stuck, as high as the Leyden phial and wire, two or three inches from the suspended mock spider. The spider is then animated by setting a charged Leyden jar at the same distance on the other side. The spider immediately jumps to the wire of the Leyden jar, bends his legs in touching it; then springs off and flies to the wire on the table; then, again, to the wire of the Leyden jar, playing with his legs against both in a very entertaining manner, and appearing perfectly alive. A single charge of the Leyden jar, in dry weather, will enable him to continue this motion for an hour or longer.

(5) A book, provided with a double line of gold around the covers, is electrified on a plate of glass in the dark. On the application of a knuckle to the gilding, the fire appears everywhere on the gold, like a flash of lightning, but not on the leather, and not even if the leather is touched instead of the gold.

(6) The electrified bumper. This consists of a small, thin

glass tumbler, nearly filled with wine, and electrified in the same manner as the Leyden jar. When brought near to the lips, a sharp electric shock is given, provided the person is closely shaved, and does not breathe on the liquor.

(7) The magic picture, an ingenious device whereby a picture, say of the King of England, constitutes in reality a Leyden jar, the outer and inner coatings consisting of concealed gold leaf placed on parts of the opposite sides of the glass plate employed for covering the picture. This was presented to a person to hold in such a manner that his hand would come in contact with one coating, while the crown of the King was placed in contact with the opposite coating. On the attempt of the person holding the picture to remove the crown from the King's head, he would receive a shock as punishment for his attempted treason. Franklin, on the other hand, holding the picture by some part not in contact with one of the coatings, could safely touch the crown.

(8) The electric jack, an ingeniously constructed electrostatic motor that was capable of rotating, even when loaded with a turkey properly prepared for cooking and placed before a fire. It was this apparatus that Franklin refers to, in a letter dated April 29, 1749, as follows: "A turkey is to be killed for our dinner by the electrical shock, roasted by the electrical jack before a fire kindled by the electrical bottle."

(9) The electrical ignition of gunpowder. The following is Franklin's description of this experiment: "A small cartridge is filled with dry powder, hard rammed, so as to bruise some of the grains; two pointed wires are then thrust in, one at each end, the points approaching each other in the middle of the cartridge till within the distance of half an inch; then, the cartridge being placed in the circle, when the four jars are discharged, the electric flame leaping from the point of one wire to the point of the other, within the cartridge amongst the powder, *fires it*, and the explosion of the powder is at the same instant with the crack of the discharge."

Franklin says, concerning this turkey, that he conceits himself that the bird killed by the shock of the Leyden jar battery was uncommonly tender. In a subsequent publication he suggests that this increase in tenderness might have been due to the rending and tearing of the flesh during the discharge, in the

manner well known to occur in the case of the passage of a discharge through such solids as wood, etc. He also attributes the tendency of an animal killed by an electric shock to undergo rapid decomposition to a similar cause.

As already remarked, these experiments were made by Franklin, for the greater part, during the first half of the year 1747. It will be remembered it was towards the close of 1745 that a discovery was made in electricity that greatly excited all electricians. This was the discovery of the Leyden jar, according to some by Von Kleist, Bishop of Pomerania, and according to others by Cuneus, of Leyden, a pupil of Muschenbroeck.

Quite naturally, we find that Franklin made a somewhat extended investigation of this electric device. Franklin's theory of electricity, as we shall shortly explain, known generally as the single-fluid theory, recognized the presence of but a single electric fluid, the differences of positive and negative excitement being, in his opinion, due to a greater and a smaller amount respectively of a hypothetical electric fluid. Consequently, as he soon discovered that when the inner coating of a Leyden jar was positively electrified, the outer coating was negatively electrified, he naturally came to the conclusion that in charging the jar, the electricity passed out from the negative coating, and entered the positive coating. In another letter to Collinson, dated September 1st, 1747, we find that Franklin soon reached the conclusion that the electric charge in the conducting coating of a Leyden jar differed from the charge in a conductor quite separated and distinct from the jar, in that in the jar the electric charge is accumulated on the surfaces of the non-electric, or, quoting the language of this letter:

(a) "The non-electric contain'd in the bottle differs when electrised from a non-electric electrised out of the bottle, in this: that the electrical fire of the latter is accumulated *on its surface*, and forms an electrical atmosphere round it of considerable extent; but the electrical fire is crowded *into the substance* of the former, the glass confining it.

(b) At the same time that the wire and top of the bottle, &c., is electrised *positively* or *plus*, the bottom of the bottle is electrised *negatively* or *minus*, in exact proportion: *i. e.*, whatever quantity of electrical fire is thrown in at the top, an equal quantity goes out of the bottom. To understand this, suppose the common quantity of electricity in each part of the bottle, before the operation begins, is equal to 20; and at every stroke of the tube, suppose a quantity equal to 1 is thrown in; then, after the first stroke, the

quantity contain'd in the wire and upper part of the bottle will be 21, in the bottom 19. After the second, the upper part will have 22, the lower 18, and so on, till, after 20 strokes, the upper part will have a quantity of electrical fire equal to 40, the lower part none: and then the operation ends: for no more can be thrown into the upper part, when no more can be driven out of the lower part. If you attempt to throw more in, it is spued back through the wire, or flies out in loud cracks through the sides of the bottle."

(a) The non-electric here referred to was one of the coatings of the Leyden jar. From a reading of this paragraph, it will be observed that Franklin believed that the electricity in a charged Leyden jar resided in the surface of the coating, forming an electrified atmosphere around it, and being kept in the coating in a crowded state where it was confined by the glass; *i. e.*, that "The electrical fire is crowded into the substance of the former (the conducting coating), the glass confining it." As we shall see, Franklin subsequently corrects this error by stating that the power of the Leyden jar to give shocks is due to the electricity accumulating on the opposite surfaces of the glass itself, the conducting coatings in contact with the two surfaces only serving to collect the charges from the innumerable points on the glass.

(b) It will be noticed here that Franklin is applying his single-fluid theory of electricity to this phenomena, since, of course, if the inner coating of the jar is electrified positively or plus, the outer coating or bottom must be electrified negatively or minus; for, from his method of looking at the phenomena, whatever amount of electricity is thrown in at the top would necessarily require an equal amount to go out at the bottom, and we find him endeavoring to figure up the condition of affairs that would result when the jar was charged to as full an extent as his electric source would permit.

In another portion of this letter to Collinson, Franklin describes the following experiments he made on the Leyden jar:

"EXPERIMENT I.

(a) "Place an electrised phial on wax: a small cork-ball suspended by a dry silk thread held in your hand, and brought near to the wire, will first be attracted, and then repelled; when in this state of repellency, sink your hand, that the ball may be brought towards the bottom of the bottle: it will be there instantly and strongly attracted, 'till it has parted with its fire.

"If the bottle had a *positive* electrical atmosphere, as well as the wire, an electrified cork would be repelled from one as well as from the other.

"EXPERIMENT II.

(b) "Fig. 1 (a) From a bent wire sticking in the table, let a small linen thread (b) hang down within half an inch of the electrised phial (c). Touch the wire of the phial repeatedly with your finger, and at every touch you will see the thread instantly attracted by the bottle. (This is best done by a vinegar cruet, or some such belly'd bottle.) As soon as you draw any fire out from the upper part, by touching the wire, the lower part of the bottle draws an equal quantity in by the thread.

"EXPERIMENT III.

(c) "Fig. 2. Fix a wire in the lead, with which the bottom of the bottle is armed (d) so as that bending upwards, its ring-end may be level with the top or ring-end of the wire in the cork (e), and at three or four inches distance. Then electrise the bottle, and place it on wax. If a cork sus-

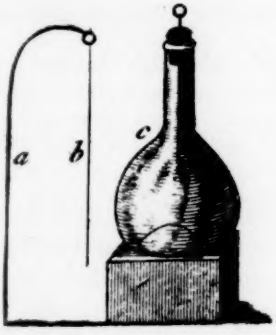


Fig. 1. Apparatus referred to in Franklin's Experiment.

Fig. 2. Apparatus referred to in Franklin's Experiment.

pended by a silk thread (f) hang between these two wires, it will play incessantly from one to the other, 'till the bottle is no longer electrised; that is, it fetches and carries fire from the top to the bottom of the bottle, 'till the equilibrium is restored."

(a) In this manner, Franklin proves that the inside and outside of the jar, *i. e.*, its inner and outer coatings, are oppositely electrified, the inside positively and the outside negatively.

(b) Here the bent wire is electrically connected with the ground, being inserted in the top of an ordinary table. A cork ball is suspended by means of a conducting thread of linen. Every time the inner coating is touched by the hand, the thread

is instantly attracted or drawn to the bottle. Franklin here considers, in accordance with his single-fluid hpyothesis, that the electric fluid is drawn out from the inner coating of the jar by touching it with the hand, an equal quantity of electricity is drawn into the lower part or outer coating of the jar when it is touched by the linen thread.

(c) In this beautiful experiment, Franklin is able to discharge a Leyden jar slowly by means of a great number of successive discharges between the inner and the outer coatings. The wire, instead of being supported on the table, as in the preceding experiment, is electrically connected with the lead that forms the outer coating of the jar. The cork is suspended by means of a silken thread midway between the two smooth metallic spheres e, e, (Fig. 2) are connected respectively with the inner and outer coatings of the jar, that it becomes midway between these two spheres. When this jar is electrified and placed on an insulating stand of wax, the cork ball continues to move between the two balls until the jar is entirely discharged.

In another letter to Collinson, dated only with the year, 1778, but apparently following the preceding letter from some reference it contains, a description is given of Franklin's further investigation of the Leyden jar.

As a result of a number of experiments made in charging and discharging the Leyden jar, which, of course, it will be impossible to discuss here for want of space, Franklin soon reaches the conclusion that the entire force of the jar, so far as its power of giving a shock is concerned, lies in the glass itself, the coating only serving the purpose of coming in contact with the sides of the glass in such a manner as to give and to receive the electricity from the several parts of the glass. This matter is referred to by Franklin as follows in this letter to Collinson, which may be spoken of as the fourth Collinson letter:

"Thus, the whole force of the bottle and power of giving a shock, is in the glass itself; the non-electrics in contact with the two surfaces, serving only to *give* and *receive* to and from the several parts of the glass; that is, to give on one side, and take away from the other.

(a) "This was discovered here in the following manner: Purposing to analyse the electrified bottle, in order to find wherein its strength lay, we placed it on glass, and drew out the cork and wire, which for that purpose

had been loosely put in. Then taking the bottle in one hand, and bringing a finger of the other near its mouth, a strong spark came from the water, and the shock was as violent as if the wire had remained in it, which showed that the force did not lie in the wire. Then, to find if it resided in the water, being crowded into and condensed in it, as confin'd by the glass, which had been our former opinion, we electrified the bottle again, and placing it on glass, drew out the wire and cork as before; then taking up the bottle, we decanted all its water into an empty bottle, which likewise stood on glass; and taking up that other bottle, we expected, if the force resided in the water, to find a shock from it; but there was none. We judged then that it must either be lost in decanting, or remain in the first bottle. The latter we find to be true; for that bottle on trial gave the shock, though filled up as it stood with fresh unelectrified water from a tea-pot. —— To find, then, whether glass had this property merely as glass, or whether the form contributed anything to it; we took a pane of sash-glass, and laying it on the hand, placed a plate of lead on its upper surface; then electrified that plate, and bringing a finger to it, there was a spark and shock. We then took two plates of lead of equal dimensions, but less than the glass by two inches every way, and electrified the glass between them, by electrifying the uppermost lead; then separated the glass from the lead, in doing which, what little fire might be in the lead was taken out, and the glass being touched in the electrified parts with a finger, afforded only very small pricking sparks, but a great number of them might be taken from different places. (b) Then dextrously placing it again between the leaden plates, and compleating a circle between the two surfaces, a violent shock ensued. —— Which demonstrated the power to reside in glass as glass, and that the non-electrics in contact served only, like the armature of a loadstone, to unite the force of the several parts, and bring them at once to any point desired: it being the property of a non-electric, that the whole body instantly receives or gives what electrical fire is given to or taken from any one of its parts."

(a) The methods followed by Franklin in this investigation give a wonderful insight into the ability of the man as an experimental philosopher. He electrifies a Leyden jar, and proposes to himself to ascertain wherein its peculiar strength lay. The jar is placed on glass for the purpose of insulating it.

In order to determine whether the force lay in the wire, which, passing through the cork at the mouth of the Leyden jar, extended down into the water which formed the inner coating of the jar, Franklin removes the cork and wire, which have been loosely placed in the jar. Then, holding the bottle in one hand, thus touching its outside coating, he brings a finger of the other hand near the mouth of the jar. As soon as the hand approaches the water, a spark comes from the water, and a shock is received, as violent as if the wire had remained

in the jar. Consequently, Franklin concludes that the force did not lie in the wire.

"But," reasoned this philosopher, "this occult force may be in the water, being crowded into and condensed in it."

In order to test this possibility, the bottle is again electrified and placed on the glass, the wire and cork drawn out as before. The bottle is then carefully taken in the hand, and its water poured into an empty Leyden jar, likewise placed on the glass. Franklin takes up this second jar, confidently expecting, if the force resides in the water, to get a shock from it, but there was none. If, then, the electric force had resided in the water, it must have been lost in the act of decanting. If not in the water, it must remain in the first bottle. This bottle, on trial, gives a shock, though filled up as it stood with fresh unelectrified water from a teapot. The conclusion is inevitable, that the force resides in the glass.

Our philosopher is still unsatisfied. Is the power of the glass to retain the shock dependent on its nature as a material, or is it by reason of the shape of the bottle? He is here possibly thinking of his experiments with pointed conductors. An ingenious experiment is made, whereby a piece of ordinary window glass is momentarily converted into a Leyden jar, and a shock taken from it. A more carefully constructed, modified Leyden jar is then made by placing on the opposite sides of a plate of glass two plates of lead of equal size, but so much smaller than the plates of glass as to leave a free space two inches around them. On electrifying the glass between these coatings, and separating the glass from the lead, the glass is found to be electrified. In this manner, however, the glass is only charged locally.

(b) While the glass plate remains electrified, Franklin places it between two leaden plates, and shows that the charge still remains in the glass, receiving as he did a violent shock from the combination. Consequently, it is proved that the power of the Leyden jar lies in the glass, and is independent of the shape of the glass, the non-electrics or conducting plates merely serving, like the armature of a loadstone, "To unite the force of the several parts, and bring them at once to any one point desired."

In a subsequent note, Franklin describes what he believes to be the manner in which the Leyden jar or bottle receives an electric charge, in accordance with his hypothesis or theory of electricity. This note is as follows:

"Place a thick plate or glass under the rubbing cushion, to cut off the communication of electrical fire from the floor to the cushion; then, if there be no fine points or hairy threads sticking out from the cushion, or from the parts of the machine opposite to the cushion, (of which you must be careful) you can get but a few sparks from the prime conductor, which are all the cushion will part with.

"Hang a phial then on the prime conductor (a), and it will not change though you hold it by the coating. —— But

"Form a communication by a chain from the coating to the cushion, and the phial will charge.

"For the globe then draws the electric fire out of the outside surface of the phial, and forces it through the prime conductor and wire of the phial, into the inside surface.

"Thus the bottle is charged with its own fire, no other being to be had while the glass plate is under the cushion.

"Hang two cork balls by flaxen threads to the prime conductor; then touch the coating of the bottle, and they will be electrified and recede from each other.

"For just as much fire as you give the coating, so much is discharged through the wire upon the prime conductor, whence the cork balls receive an electrical atmosphere. —— But

"Take a wire bent in the form of a C (b), with a stick of wax fixed to the outside of the curve, to hold it by; and apply one end of this wire to the coating, and the other at the same time to the prime conductor, the phial will be discharged; and if the balls are not electrified before the discharge, neither will they appear to be so after the discharge, for they will not repel each other.

"Now if the fire discharged from the inside surface of the bottle through its wire, remained on the prime conductor, the balls would be electrified, and recede from each other.

"If the phial really exploded at both ends, and discharged fire from both coating and wire, the balls would be *more* electrified, and recede *farther*; for none of the fire can escape, the wax handle preventing.

"But if the fire, with which the inside surface is surcharged, be so much precisely as is wanted by the outside surface, it will pass round through the wire fixed to the wax handle, restore the equilibrium in the glass, and make no alteration in the state of the prime conductor.

"Acordingly we find, that if the prime conductor be electrified, and the cork balls in a state of repellency before the bottle is discharged, they continue so afterwards. If not, they are not electrified by that discharge."

(a) PRIME CONDUCTOR: That conductor of the electrical

machine which collects positive electricity. This part of the frictional machine was first employed by Bose.

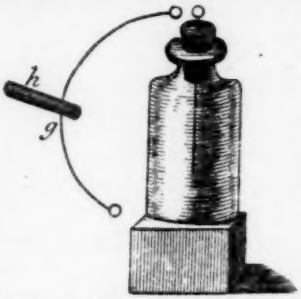


Fig. 3. Franklin's form of Discharging Rod.

(b) The wire bent in the form of the letter C, represents what is well known as the discharging rod. This apparatus is represented in Fig. 3. As will be seen, the ends of the wire are provided with smooth metallic spheres soldered to them. The stick of wax employed for supporting the wires is represented at H.

At a later date, Franklin conducted some experiments with the view of ascertaining how long a Leyden bottle, properly charged and hermetically sealed, will retain its electricity:

"I formerly had an opinion that a Leyden bottle, charg'd and then seal'd hermetically, might retain its electricity forever; but having afterwards some suspicion that possibly that subtil fluid might, by slow imperceptible degrees, soak through the glass, and in time escape, I requested some of my friends, who had conveniences for doing it, to make trial, whether, after some months, the charge of a bottle so sealed would be sensibly diminished. Being at Birmingham, in September, 1760, Mr. Bolton of that place, opened a bottle that had been charged, and its long tube neck hermetically sealed in the January preceding. On breaking off the end of the neck, and introducing a wire into it, we found it possessed of a considerable quantity of electricity, which was discharged by a snap and spark. This bottle had lain near seven months on a shelf, in a closet, in contact with bodies that would undoubtedly have carried off all its electricity, if it could have come readily through the glass. Yet, as the quantity manifested by the discharge was not apparently so great as might have been expected from a bottle of that size well charged, some doubt remained whether part had escaped while the neck was sealing, or had since, by degrees, soaked through the glass. But an experiment of Mr. Canton's, in which such a bottle was kept under water a week, without having its electricity in the least impaired, seems to show, that when the glass is cold, though extremely thin, the electric fluid is well retained by it. As that ingenious and accurate experimenter made a discovery, like yours, of the effect of heat in rendering thin glass permeable by that fluid, it is but doing him justice to give you his account of it, in his own words, extracted from his letter to me, in which he communicated it, dated Oct. 31, 1760, viz.

"'Having procured some thin glass balls, of about an inch and a half in diameter, with stems, or tubes, of eight or nine inches in length, I electrified them, some positively on the inside, and others negatively, after

the manner of charging the Leyden bottle, and sealed them hermetically. Soon after I applied the naked balls to my electrometer, and could not discover the least sign of their being electrical; but holding them before the fire, at the distance of six or eight inches, they became strongly electrical in a very short time, and more so when they were cooling. These balls will, every time they are heated, give the electrical fluid to, or take it from other bodies, according to the plus or minus state of it within them. Heating them frequently, I find will sensibly diminish their power; but keeping one of them under water a week, did not appear in the least to impair it. That which I kept under water, was charged on the 22d of September last, was several times heated before it was kept in water, and has been heated frequently since, and yet it still retains its virtue to a very considerable degree. The breaking two of my balls accidentally, gave me an opportunity of measuring their thickness, which I found to be between seven and eight parts in a thousand of an inch.

"A down feather, in a thin glass ball, hermetically sealed, will not be affected by the application of an excited tube, or the wire of a charged vial, unless the ball be considerably heated; and if a glass pane be heated till it begins to grow soft, and in that state be held between the wire of a charged vial, and the discharging wire, the course of the electrical fluid will not be through the glass, but on the surface, round by the edge of it.'"

There were two rival hypotheses or theories of electricity that were entertained by physicists in the time of Franklin; *i. e.*, the single-fluid hypothesis propounded by Franklin, and the double-fluid hypothesis propounded by Symmer of Dufay. Franklin's hypothesis, propounded in 1749,, asserted that all electrical phenomena were due to the presence of a single, extremely tenuous and practically weightless or imponderable electric fluid, that exists in all matter. That the particles of the electric fluid were mutually repellent, but were attracted by all kinds of matter. All kinds of matter are capable of containing a certain quantity of the electric fluid without manifesting any excitement. If, however, a body contains either a surplus or a deficit, it at once manifests electric excitement. During electrification by friction, an excess of the fluid is given to one body, thus imparting to it a positive excitement, leaving the other body with a deficit of the fluid, thereby rendering it negatively excited.

The double-fluid hypothesis assumed that all kinds of matter contained an indefinite quantity of an imponderable neutral electric fluid, formed by the combination of two separate electric fluids; *i. e.*, the positive and the negative. That in unelectrified matter these two fluids combine and neutralize each

other, the act of electrification consisting in their separation. According to this hypothesis, when a body is electrified by friction, the work done, resulting as it does in the separation of the two fluids, the rubber will retain one electric fluid and the thing rubbed the other electric fluid, so that the rubber and the thing rubbed acquire opposite electric excitements.

According to either theory, both the rubber and the thing rubbed will be electrified with opposite electrification. If, however, the thing rubbed consists of some conducting substances like metallic bodies, any electric excitement it attains will be rapidly lost by the escape of the fluid through the body of the person holding it to the ground. If, however, the piece of metal be insulated in any way, as by supporting it in a glass handle, the metal can be as readily electrified as a bit of glass or sealing wax.

Franklin formed his single-fluid hypothesis or theory of electricity very early in his experiments with the tube received from Mr. Collinson. Although this hypothesis is not credited at the present time, yet it forms a very convenient means for explaining phenomena, and we find that Franklin, in all of his subsequent work, constantly had resource to this theory in endeavoring to picture to himself and to his readers the manner in which the phenomena occurred; for example, in his second letter to Collinson, dated July 11, 1747, he speaks as follows regarding the manner in which he understands that a body is electrified by friction, and explains by this hypothesis the manner in which, as he understands it, it is possible to electrify people that are insulated from the earth; *i. e.*, while standing on cakes of wax.

(a) "We had for some time been of opinion, that the electrical fire was not created by friction, but collected, being really an element diffus'd among, and attracted by other matter, particularly by water and metals. We had even discovered and demonstrated its afflux to the electrical sphere, as well as its efflux, by means of little light windmill wheels made of stiff paper vanes, fixed obliquely and turning freely on fine wire axes. Also by little wheels of the same matter, but formed like water-wheels. Of the disposition and application of which wheels, and the various phaenomena resulting, I could, if I had time, fill you a sheet. The impossibility of electrising one's self (though standing on wax) by rubbing the tube, and drawing the fire from it; and the manner of doing it, by passing the tube near a per-

son or thing standing on the floor, etc., had also occurred to us some months before Mr. *Watson's* ingenious Sequel came to hand, and these were some of the new things I intended to have communicated to you. —— But now I need only mention some particulars not hinted in that piece, with our reasonings thereupon; though perhaps the latter might well enough be spared.

(b) "1. A person standing on wax, and rubbing the tube, and another person on wax drawing the fire, they will both of them, (provided they do not stand so as to touch one another) appear to be electrised to a person standing on the floor; that is, he will perceive a spark on approaching each of them with his knuckle.

"2. But if the persons on the wax touch one another during the exciting of the tube, neither of them will appear to be electrised.

"3. If the touch of of one another after exciting the tube, and drawing the fire as aforesaid, there will be a stronger spark between them, than was between either of them and the person on the floor.

"4. After such strong spark, neither of them discover any electricity.

(c) "These appearances we attempt to account for thus: We suppose as aforesaid, that electrical fire is a common element, of which every one of the three persons above mentioned has his equal share, before any operation is begun with the tube. A, who stands on wax and rubs the tube, collects the electrical fire from himself into the glass: and his communication with the common stock being cut off by the wax, his body is not again immediately supply'd. B, (who stands on wax likewise) passing his knuckle along near the tube, receives the fire which was collected by the glass from A; and his communication with the common stock being likewise cut off, he retains the additional quantity received. —— To C, standing on the floor, both appear to be electrised: for he having only the middle quantity of electrical life, receives a spark upon approaching B, who has an over quantity; but gives one to A, who has an under quantity. If A and B approach to touch each other, the spark is stronger, because the difference between them is greater: After such touch there is no spark between either of them and C, because the electrical fire in all is reduced to the original equality. If they touch while electrising, the equality is never destroyed, the fire only circulating. (d) Hence, have arisen some new terms among us: we say, B, (and bodies like circumstanced) is electrised *positively*; A, *negatively*. Or rather, B is electrised *plus*; A, *minus*. And we daily in our experiments electrise bodies *plus* or *minus*, as we think proper. * * * To electrise *plus* or *minus*, no more needs to be known than this, that the parts of the tube or sphere that are rubbed, do, in the instant of the friction, attract the electrical fire, and therfore take it from the thing rubbing: the same parts immediately, as the friction upon them ceases, are disposed to give the fire they have received, to any body that has less. Thus you may circulate it, as Mr. *Watson* has shewn; as you connect that body with the rubber or with the receiver, the communication with the common stock being cut off. We think that ingenious gentleman was deceived when he imagined (in his Sequel) that the electrical fire came down the wire from the ceiling to the gun-barrel, thence to the sphere, and so electrised the

machine and the man turning the wheel, etc. We suppose it was *driven off*, and not brought on through that wire; and that the machine and man, etc., were electrised *minus*; *i. e.*, had less electrical fire in them than things in common."

Here it will be noted that Franklin states he had, for a long time, believed that electricity is not produced by friction, but is collected from matter in which it has been originally diffused. In other words, the conception of the single-fluid theory of electricity evidently came with his first investigations.

He notes very clearly the fact that if two people are standing on wax at a short distance from each other, one rubbing the tube and the other taking the electric sparks that are produced by the friction, they will, provided that they do not touch each other, both appear to be electrified to a person standing on the floor; that is, either will give a spark to a person standing on the floor who approaches them with his knuckle. Neither of these people will appear electrified, although they stand on the wax, if they touch each other during the rubbing of the tube. If, however, they touch each other after the rubbing of the tube, although a spark will pass between them, yet after such spark passes, neither of them will manifest any electric excitement.

Note, now, Franklin's application of his single-fluid hypothesis to the above phenomena. Calling the persons that stand on the two cakes of wax A and B, and the person standing on the floor C, suppose A rubs the tube. According to Franklin, he simply passes the electric fluid from himself into the glass. Since his communication with the common stock of electric fluid is cut off by the insulating power of the wax, his body is not again immediately supplied with electricity. B, holding his knuckle near the tube, receives the electricity which was collected by A, on the glass, and his communication being cut off from the common supply, he retains this additional quantity. To C, standing on the floor, both appear to be electrified, for C, having only a neutral quantity of electricity, receives a spark on approaching B, who has a surplus of the fluid, and gives one to A, who has a deficit of the fluid. If A and B approach so as to touch each other, a spark passes, but after such passage, neither of them appear electrified, because they have regained the amount of electricity they originally possessed.

Franklin applies the term positively electrified to B; *i. e.*, the one who has received into his body an additional quantity of electricity, taking it, as he had, from the excited glass tube; therefore B, was also said to be electrified plus. A, from whose body the surplus of electricity received from B, was obtained, and who, therefore, had a deficit of electricity, was negatively excited, who had a minus electrification.

There can be no doubt that to Franklin is due the credit of the great discovery of the positive and negative condition of electric excitement. It is true that the honor of this discovery has been credited by the English to Dr. Watson, but Watson's paper on this subject is dated January 28th, 1748, while this letter of Franklin; *i. e.*, the second letter to Mr. Collinson, was dated July 11, 1747. Moreover, as will be noted in the beginning of this quotation, Franklin says: "We had for some time been of the opinion," etc.

At a date prior to July 11, 1747, when Franklin first published his distinction between positive and negative electric excitement, a Frenchman, Dufay, observed that two different kinds of electric excitement are produced by rubbing glass and sulphur respectively. He called these two kinds of electricity vitreous, or that produced by glass, and resinous, or that produced by resins, pointing out the fact that rock crystal, precious stones, the wool or hair of animals, together with many other bodies, likewise produce vitreous electricity, while such bodies as amber, copal, gum lac, silk, paper, thread, etc., produc resinous electricity. He, however, pointed out the fact that a body charged with vitreous electricity possessed the power of attracting all bodies charged with resinous electricity but repelled other bodies charged with vitreous electricity, and that, on the contrary, a body charged with resinous electricity attracted all other bodies charged with vitreous electricity, and repelled all bodies charged with resinous electricity.

Kindersley communicated Dufay's discovery to Franklin, a discovery which otherwise seemed to have remained unnoticed by the scientific world. Franklin studied these phenomena, and soon came to the conclusion that the vitreous and resinous electricity were, in reality, nothing other than positive and negative electricity.

At a later date, *i. e.*, 1749, Franklin published the following paper, describing more fully his single-fluid theory of electricity:

(a) Opinions and Conjectures, concerning Properties and Effects of the electrical matter, arising from Experiments and Observations, (b) made at Philadelphia, 1749.

"1. The electrical matter consists of particles extremely subtile, since it can permeate common matter, even the densest metals, with such ease and freedom as not to receive any preceptible resistance.

(c) "2 If any one should doubt whether the electrical matter passes through the substance of bodies, or only over and along their surfaces, a shock from an electrified large glass jar, taken through his own body, will probably convince him.

(d) "3. Electrical matter differs from common matter in this, that the parts of the latter mutually attract, those of the former mutually repel, each other. Hence the appearing divergency in a stream of electrified effluvia.

"4. But though the particles of electrical matter do repel each other, they are strongly attracted by all other matter.

5. From these three things, the extreme subtilty of the electrical matter, the mutual repulsion of its parts, and the strong attraction between them and other matter, arise this effect, that, when a quantity of electrical matter is applied to a mass of common matter of any bigness or length, within our observation (which hath not already got its quantity) it is immediately and equally diffused through the whole.

(e) "6. Thus common matter is a kind of a spunge to the electrical fluid. And as a spunge would receive no water if the parts of water were not smaller than the pores of the spunge; and even then but slowly, if there were not a mutual attraction between those parts and the parts of the spunge; and would still imbibe it faster, if the mutual attraction among the parts of the water did not impede, some force being required to separate them; and fastest, if, instead of attraction, there were a mutual repulsion among those parts, which would act in conjunction with the attraction of the spunge. So is the case between the electrical and common matter.

(f) "7. But in common matter there is (generally) as much of the electrical as it will contain within its substance. If more is added, it lies without upon the surface, and forms what we call an electrical atmosphere; and then the body is said to be electrified.

"8. 'Tis supposed, that all kinds of common matter do not attract and retain the electrical, with equal strength and force, for reasons to be given hereafter. And that those called electrical *per se*, as glass, &c., attract and retain it strongest, and retain the greatest quantity.

(g) "9. We know that the electrical matter is *in* common matter, because we can pump it *out* by the globe or tube. We know that common matter has near as much as it can contain, because, when we add a little more to any portion of it, the additional quantity does not enter, but forms an electrical atmosphere. And we know that common matter has not (generally) more than it can contain, otherwise all loose portions of it would repel each

other, as they constantly do when they have electric atmospheres."

* * * * * * *

(h) "15. The form of the electrical atmosphere is that of the body it surrounds. This shape may be rendered visible in a still air, by raising a smoke from dry rosin, dropt into a hot tea-spoon under the electrised body, which will be attracted, and spread itself equally on all sides, covering and concealing the body. And this form it takes because it is attracted by all parts of the surface of the body, though it cannot enter the substance already replete. Without this attraction, it would not remain round the body, but dissipate in the air.

(i) "16. The atmosphere of electrical particles surrounding an electrified sphere, is not more disposed to leave it, or more easily drawn off from any one part of the sphere than from another, because it is equally attracted by every part. But that is not the case with bodies of any other figure. From a cube it is more easily drawn at the corners than at the plane sides, and so from the angles of a body of any other form, and still most easily from the angle that is most acute. Thus if a body shaped as A, B, C, D, E, in Fig. 8 (our

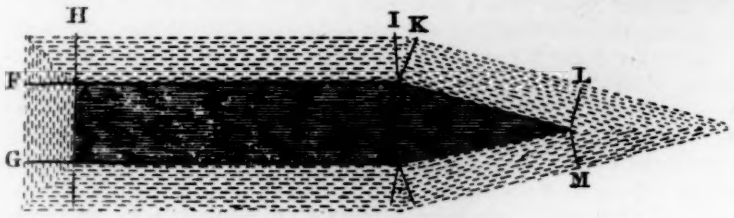


Fig. 4. Franklin's explanation of the power of points in discharging electrified body.

Fig. 4) be electrified or have an electrical atmosphere communicated to it, and we consider every side as a base on which the particles rest, and by which they are attracted, one may see, by imagining a line from A to F, and another from E to G, that the portion of the atmosphere include in F, A, E, G, has the line A E for its basis. So the portion of atmosphere include in H, A, B, I, has the line A, B, for its basis. And likewise, the portion included in K, B, C, L, has B, C, to rest on; and so on the other side of the figure. Now if you would draw off this atmosphere with any blunt, smooth body, and approach the middle of the side A, B, you must come very near, before the force of your attractor exceeds the force or power with which that side holds its atmosphere. But there is a small portion between I, B, K, that has less of the surface to rest on, and to be attracted by, than the neighbouring portions, while at the same time there is a mutual repulsion between its particles, and the particles of those portions, therefore here you can get it with more ease, or at a greater distance. Betwen F, A, H, there is a larger portion that has yet a less surface to rest on, and to attract it; here, therefore, you can get it away still more easily. But easiest of all between L, C, M, where the quantity is largest, and the surface to attract and keep it back the least. When you have drawn away one of these angular portions of the fluid, another succeeds in its place, from the nature

of fluidity and the mutual repulsion beforementioned; and so the atmosphere continues flowing off at such angle, like a stream, till no more is remaining. The extremities of the portions of atmosphere over these angular parts, are likewise at a greater distance from the electrified body, as may be seen by the inspection of the above figures; the point of the atmosphere of the angle C, being much farther from C, than any other part of the atmosphere over the lines C, B, or B, A: And, besides the distance arising from the nature of the figure, where the attraction is less, the particles will naturally expand to a greater distance by their mutual repulsion. "On these accounts we suppose electrified bodies discharge their atmosphere upon unelectrified bodies more easily, and at a greater distance from their angles and points than from their smooth sides. —— Those points will also discharge into the air, when the body has too great an electrical atmosphere, without bringing any non-electric near, to receive what is thrown off:" For the air, though an electric *per se*, yet has always more or less water and other non-electric matters mixed with it: and these attract and receive what is so discharged.

(j) "17. But points have a property, by which they *draw on* as well as *throw off* the electrical fluid, at greater distances than blunt bodies can. That is, as the pointed part of an electrified body will discharge the atmosphere of that body, or communicate it farthest to another body, so the point of an unelectrified body will draw off the electrical atmosphere from an electrified body, farther than a blunter part of the same unelectrified body will do. Thus a pin held by the head, and the point presented to an electrified body, will draw off its atmosphere at a foot distance: where, if the head were presented instead of the point, no such effect would follow. To understand this, we may consider, that if a person standing on the floor would draw off the electrical atmosphere from an electrified body, an iron crow and a blunt knitting-needle held alternately in his hand, and presented for that purpose, do not draw with different forces in proportion to their different masses. For the man, and what he holds in his hand, be it large or small, are connected with the common mass of unelectrified matter; and the force with which he draws is the same in both cases, it consisting in the different proportion of electricity in the electrified body, and that common mass. But the force with which the electrified body retains its atmosphere by attracting it, is proportioned to the surface over which the particles are placed; *i. e.* four square inches of that surface retain their atmosphere with four times the force that one square inch retains its atmosphere. And as in plucking the hairs from the horse's tail, a degree of strength not sufficient to pull away a handful at once, could yet easily strip it hair by hair; so a blunt body presented cannot draw off a number of particles at once, but a pointed one, with no greater force, takes them away easily, particle by particle.

(k) "18. These explanations of the power and operation of points, when they first occurr'd to me, and while they first floated in my mind, appeared perfectly satisfactory; but now I have wrote them, and considered them more closely in black and white, I must own I have some doubts about

them; yet, as I have at present nothing better to offer in their stead, I do not cross them out: for even a bad solution read, and its faults discovered, has often given rise to a good one, in the mind of an ingenious reader.

"19. Nor is it of much importance to us, to know the manner in which nature executes her laws; 'tis enough if we know the laws themselves. 'Tis of real use to know that china left in the air unsupported will fall and break; but *how* it comes to fall, and *why* it breaks, are matters of speculation. 'Tis a pleasure indeed to know then, but we can preserve our china without it."

(a) Note the modest title of this paper: "Opinions and Conjectures Concerning the Properties and Effects of Electrical Matter, Arising from Experiments and Observations, Made at Philadelphia, 1749." Franklin evidently does not desire all these statements to be regarded as worthy of the name Opinions, but states some of them as conjectures. The distinction here drawn appears to be the same as that which would be drawn to-day between theories and hypotheses.

(b) "Made at Philadelphia." Although practically the experiments made at Philadelphia were all Franklin's yet he generally uses the phrase, Experiments made at Philadelphia, rather than Experiments made by me, or by Dr. Franklin, at Philadelphia.

(c) An unquestionably convincing proof. Franklin quaintly remarks that, if any one doubts the ability of a discharge from a large glass jar to pass through one's body, let him try it, and the result "Will probably convince him."

Fig. 5. Appearance of positive or brush discharge (Von Marum)

(d) Franklin appears to have obtained a clear idea of the fact that a stream of electrified particles, called by him the electrified effluvia, passing from a charged conductor (positive), assumes the well known divergent appearance characteristic of the positive electric brush, or convective discharge, since he correctly ascribes the cause of this phenomena to the mutual repulsion of similarly charged particles. This discharge con-

sists, as now known, of streams of both electrified air particles and minute particles of the metal of the pointed electrode (Franklin's effluvia) that diverge from one another under the influence of their mutual repulsion. Fig. 5 represents the appearance of such a discharge as obtained by Von Marum, by the use of his powerful frictional electric machine.

(e) "Thus common matter is a kind of sponge to the electric fluid." Franklin clearly teaches in this hypothesis that there is a certain quantity of electric fluid which matter is capable of absorbing without manifesting its presence. He cites here the correct illustration of a sponge, which, as is well known, is capable of absorbing a certain quantity of water without parting with the same, unless it is compressed or shaken. It would clearly be impossible for the water to be absorbed by the sponge were not the particles of water smaller than the pores or openings in the sponge, and that even then, this absorption would take place but slowly did not a mutual attraction exist between the particles of the sponge and the particles of the water. Moreover, that the sponge would possess the power of absorbing the water more rapidly if the mutual attraction between the particles of the water did not prevent them from entering the sponge; that is, if what we call cohesion did not oppose itself to the particles leaving one another and entering the mass of the sponge. And finally, if, instead of the particles of the water which was being absorbed by the sponge, possessing cohesion, and to that extent, resisting entrance into the mass of the sponge, they possessed the property of mutual repulsion, this repulsion would act in the same direction as the attraction of the sponge, and would, therefore, increase the speed with which the water would enter it. As will be seen, the reasoning here is both concise and complete, characteristics common in Franklin's experimental investigation.

(f) "Forms what we call an electrical atmosphere." It will be observed that Franklin uses the term electrical atmosphere in the same sense as the electrification of a body, his conception of positive electrification being substantially as follows: That ordinary unelectrified matter contains no more of the electrical fluid than it can contain in its substance. When an additional

amount is added, this additional quantity must reside on the surface. This is what is called at electrical atmosphere, and the body is, therefore, electrified (positively).

(g) Here Franklin gives his reasons for the single-fluid hypothesis. He concludes that the electric fluid resides in all common matter since it can be taken out either by means of the globe (electrical machine) or of the tube, the frictional device employed for obtaining electricity. That ordinary matter possesses about as much as it can contain of this electric fluid is shown since if a little more is added, this quantity does not enter, but forms the electric atmosphere, and that ordinary matter has not generally more than it can contain is seen from the fact that if it had, all additional or loose particles would repel one another, as all bodies do that possess electrical atmospheres.

(h) "The form of the electrical atmosphere is that of the body it surrounds." In order to render this visible, the electrified body is surrounded by a smoke, produced by the simple experiment of dropping dry rosin in a hot teaspoon held under the electrified body. This smoke, being attracted by the charged body, spreads itself around the body under the influence of the electric charge.

(i) Here again Franklin reverts to the power of points, which he had already discussed in his second letter to Collinson, dated July 11, 1747. In this paragraph he gives an excellent explanation as to the effect produced by the shape of an electrified body on the distribution of its atmosphere of electrified particles. For example, in the case of a sphere, the depth of this atmosphere should be uniform over all portions of the surface, since the mass of the sphere attracts them equally at every point. The same, however, would not be true with bodies of any other figure; for example, in case of a cube, the electrical atmosphere, or the electricity, could be more readily drawn from any of the corners than it could from the plane sides; and in general, in the case of any irregular figure, the electrical atmosphere can be drawn most easily from the sharpest or most acute angle; thus, if a body shaped as A,B,C,D,E, Fig. 4, be electrified, and a

blunt body be approached to it on different sides, it will be more difficult to draw off the electrical charge when approached to a point midway between A and E, or between A and B, or E and D, since at these points the fluid is held on to the charged body by a portion that has AE, AB, or ED, for its base. If, however, a blunt smooth body be approached to the point C, there will be a greater area of such blunt body opposed to C, for at C, the surface of the body that the charge has to rest on is much less that that of the approached body. Hence, the charge will readily leave the body at this point. Moreover, as Franklin points out, at points of a charged body, as, for example, at C, in Fig. 4, the mutual repulsion of the particles of electricity constituting the electrified atmosphere may result in causing such points to discharge the electricity into the air whenever the charged body possesses too great an electrical atmosphere.

(j) "But points have a property by which they draw on, as well as throw off the electrical fluid, at greater distances than blunt bodies can." Franklin here gives a quaint explanation based on the analogy of plucking hairs from the tail of a horse, calling attention to the fact that, while a certain force exerted to pull out simultaneously the hairs from an area of the tail of the horse, equal approximately to the quarter of a square inch, might be totally inadequate to remove any of the hairs, yet that the same force would probably suffice readily to remove them one by one. In a similar manner, that if a blunt body be approached to the plane surface of an electrified body, and an endeavor is made to remove simultaneously a number of electrified particles from a certain area of such surface, say a square inch, it might not be able to overcome the attraction existing between the gross matter and the electrical atmosphere; whereas, if it attempted to remove the electrified particles a few at a time, as by approaching the point of a charged conductor, it might readily be able to overcome the attraction existing between the limited amount of matter at such point, and its electrical atmosphere.

(k) Note here the unquestioned mental integrity of the man, and his candid confession that, while the preceding explanations appeared to him, when they first suggested themselves to

his mind, perfectly satisfactory, yet when he sees them written in cold black and white, he begins to doubt their probability. "I must own I have some doubts about them; yet, as I have at present nothing better to offer in their stead, I do not cross them out; for even a bad solution read, and its faults discovered, has often given rise to a good one in the mind of an ingenious reader."

Then again, note in the next paragraph his quaint reflections on the laws of nature, and the practical value that we can obtain from a knowledge of such laws. While no one can question the use of the knowledge that china, left unsupported in the air, will fall and break; "But how it comes to fall, and why it breaks, are matters of speculation;" and this statement would remain true to the present day. "'Tis a pleasure indeed," says Franklin, "to know them, but we can preserve our china without it."

Note in a similar manner the following quotations taken from a letter written in September, 1755, to Collinson:

"These thoughts, my dear friend, are many of them crude and hasty; and if I were merely ambitious of acquiring some reputation in philosophy, I ought to keep them by me, till corrected and improved by time and farther experience. But since even short hints and imperfect experiments in any branch of science, being communicated, have oftentimes a good effect, in exciting the attention of the ingenious to the subject, and so become the occasion of more exact disquisition, and more complete discoveries. You are at liberty to communicate this paper to whom you please; it being of more importance that knowledge should increase, than that your friend should be thought an accurate philosopher."

But leaving the above important paper by Franklin on the properties and effects of electric matter, especially as regards the influence of points on the discharge of electrified bodies, careful reference should be made to some additional statements in this article. It is especially important since these statements have a bearing on a discussion that has recently existed among scientific circles as to whether Franklin should be given the credit for first actually demonstrating the identity of lightning and electricity, or whether such credit should be assigned to Dalibard, De Romas, or others. The additional matter above referred to, as contained in the article written in 1749, is as follows:

(a) "20. Thus in the present case, to know this power of points, may possibly be of some use to mankind, though we should never be able to explain it. The following experiments, as well as those in my first paper, shew this power. I have a large prime conductor, made of several thin sheets of clothier's pasteboard, form'd into a tube, near ten feet long and a foot diameter. It is cover'd with *Dutch* emboss'd paper, almost totally gilt. This large metallic surface supports a much greater electrical atmosphere than a rod of iron of 50 times the weight would do. It is suspended by silk lines, and when charged will strike at near two inches distance, a pretty hard stroke so as to make one's knuckle ache. Let a person standing on the floor present the point of a needle at 12 or more inches distance from it, and while the needle is so presented, the conductor cannot be charged, the point drawing off the fire as fast as it is thrown on by the electrical globe. Let it be charged, and then present the point at the same distance, and it will suddenly be discharged. In the dark you may see a light on the point, when the experiment is made. And if the person holding the point stands upon wax, he will be electrified by receiving the fire at that distance. Attempt to draw off the electricity with a blunt body, as a bolt of iron round at the end, and smooth (a silversmith's iron punch, inch thick), is what I use, and you must bring it within the distance of three inches before you can do it, and then it is down with a stroke and crack. As the pasteboard tube hangs loose on silk lines, when you approach it with the punch iron, it likewise will move towards the punch, being attracted while it is charged; but if, at the same instant, a point be presented as before, it retires again, for the point discharges it. Take a pair of large brass scales, of two or more feet beam, the cords of the scales being silk. Suspend the beam by a packthread from the ceiling, so that the bottom of the scales may be about a foot from the floor: The scale will move around in a circle by the untwisting of the pack-thread. Set the iron punch on the end upon the floor, in such a place as that the scales may pass over it in making their circle: Then electrify one scale, by applying the wire of a charged phial to it. As they move round, you see that scale draw nigher to the floor, and dip more when it comes over the punch; and if that be placed at a proper distance, the scale will snap and discharge its fire into it. But if a needle be stuck on the end of the punch, its point upwards, the scale, instead of drawing nigh to the punch, and snapping, discharges its fire silently through the point, and rises higher from the punch. Nay, even if the needle be placed upon the floor near the punch, its point upwards, the end of the punch, tho' so much higher than the needle, will not attract the scale and receive its fire, for the needle will get it and convey it away, before it comes nigh enough for the punch to act. And this is constantly observable in these experiments, that the greater quantity of electricity on the pasteboard tube, the farther it strikes or discharges its fire, and the point likewise will draw it off at a still greater distance.

(b) "Now, if the fire of electricity and that of lightning be the same, as I have endeavored to shew at large, in a former paper, this pasteboard tube and these scales may represent electrified clouds. If a tube of only ten feet

long will strike and discharge its fire on the punch at two or three inches distance, an electrified cloud of perhaps 10,000 acres may strike and discharge on the earth at a proportionably greater distance. The horizontal motion of the scales over the floor, may represent the motion of the clouds over the earth; and the erect iron punch, a hill or high building; and then we see how electrified clouds passing over hills or high buildings at too great a height to strike, may be attracted lower till within their striking distance. And lastly, if a needle fixed on the punch with its point upright, or even on the floor below the punch, will draw the fire from the scale silently at a much greater than the striking distance, and so prevent its descending towards the punch; or if in its course it would have come nigh enough to strike, yet being first deprived of its fire it cannot, and the punch is thereby secured from the stroke. (c) I say, if these things are so, may not the knowledge of this power of points be of use to mankind, in preserving houses, churches, ships, &c., from the stroke of lightning, by directing us to fix on the highest parts of those edifices, upright rods of iron, made sharp as a needle, and gilt to prevent rusting, and from the foot of those rods a wire down the outside of the building into the ground, or down round one of the shrouds of a ship, and down her side till it reaches the water? Would not these pointed rods probably draw the electrical fire silently out of a cloud before it came nigh enough to strike, and thereby secure us from that most sudden and terrible mischief?

(d) "21. To determine the question, whether the clouds that contain lightning are electrified or not, I would propose an experiment to be try'd where it may be done conveniently. On the top of some high tower or steeple, place a kind of sentry-box (as in Fig. 9) (our Fig. 6) big enough to contain a man and an electric stand. From the middle of the stand let an iron rod rise and pass bending out of the door, and then upright 20 or 30 feet, pointed very sharp at the end. If the electrical stand be kept clean and dry, a man standing on it when such clouds are passing low, might be electrified and afford sparks, the rod drawing fire to him from a cloud. If any danger to the man should be apprehended (though I think there would be none) let him stand so the sparks, if the rod is electrified, will strike from the rod to the wire, on the floor of his box, and now and then bring near to the rod the loop of a wire that has one end fastened to the leads, he holding it by a wax handle; and not affect him.

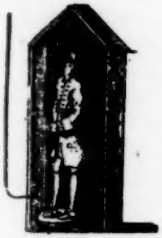


Fig. 6. The forerunner of the lightning rod.

(e) "22. Before I leave this subject of lightning, I may mention some other similarities between the effects of that, and those of electricity. Lightning has often been known to strike people blind. A pigeon that we struck dead to appearance by the electrical shock, recovering life, drooped about the yard several days, eat nothing, though crumbs were thrown to it, but declined and died. We did not think of it being deprived of sight; but afterwards a pullet struck dead in like manner, being recovered by repeatedly blowing into its lungs, when set down on the floor, ran headlong against

the wall, and on examination appeared perfectly blind. Hence we concluded the pigeon also had been absolutely blinded by the shock. The biggest animal we have yet killed, or tried to kill, with the electrical stroke, was a well-grown pullet.

(i) "23. Reading in the ingenious Dr. Miles's account of the thunder storm at Stretham, the effect of the lightning in stripping off all the paint that had covered a gilt moulding of a panel of wainscot, without hurting the rest of the paint, I had a mind to lay a coat of paint over the filletting of gold on the cover of a book, and try the effect of a strong electrical flash sent through that gold from a charged sheet of glass. But having no paint at hand, I pasted a narrow strip of paper over it; and when dry, sent the flash through the gilding, by which the paper was torn off from end to end, with such force, that it was broken in several places, and in others brought away part of the grain of the Turkey-leather in which it was bound; and convinced me, that had it been painted, the paint would have been stript off in the same manner with that on the wainscot at Stretham.

"24. Lightning melts metals, and I hinted in my paper on that subject, that I suspected it to be a cold fusion; I do not mean a fusion by force of cold, but a fusion without heat. (g) We have also melted gold, silver, and copper, in small quantities, by the electrical flash. The manner is this: Take leaf gold, leaf silver, or leaf gilt copper, commonly called leaf brass, or *Dutch gold*; cut off from the leaf long narrow strips, the breadth of a straw. Place one of these strips between two strips of smooth glass that are about the width of your finger. If one strip of gold, the length of the leaf, be not long enough for the glass, add another to the end of it, so that you may have a little part hanging out loose at each end of the glass. Bind the pieces of glass together from end to end with strong silk thread; then place it so as to be part of an electrical circuit, (the ends of gold hanging out being of use to join with the other parts of the circuit) and send the flash through it, from a large electrified jar or sheet of glass. Then if your strips of glass remain whole, you will see that the gold is missing in several places, and instead of it a metallic stain on both the glasses; the stains on the upper and under glass exactly similar in the minutest stroke, as may be seen by holding them to the light; the metal appeared to have been not only melted, but even vitrified, or otherwise so driven into the pores of the glass as to be protected by it from the action of the strongest Aqua Fortis, or Aqua Regia. I send you enclosed two little pieces of glass with these metallic stains upon them, which cannot be removed without taking part of the glass with them. Sometimes the stain spreads a little wider than the breadth of the leaf, and looks brighter at the edge, as by inspecting closely you may observe in these. Sometimes the glass breaks to pieces; once the upper glass broke into a thousand pieces, looking like coarse salt. These pieces I send you were stain'd with *Dutch gold*. True gold makes a darker stain, somewhat reddish; silver, a greenish stain. We once took two pieces of thick looking-glass, as broad as a *Gunter's* scale, and six inches long; and placing leaf-gold between them, put them between two smoothly plain'd pieces of wood, and fix'd them tight in a book-binder's small press; yet

though they were so closely confined, the force of the electrical shock shivered the glass into many pieces. The gold was melted, and stain'd into the glass, as usual. The circumstances of the breaking of the glass differ much in making the experiment, and sometimes it does not break at all: but this is constant, that the stains in the upper and under pieces are exact counterparts of each other. And though I have taken up the pieces of glass between my fingers immediately after this melting, I never could perceive the least warmth in them.

"25. In one of my former papers, I mentioned, that, gilding on a book, though at first it communicated the shock perfectly well, yet failed after a few experiments, which we could not account for. We have since found that one strong shock breaks the continuity of the gold in the filletting and makes it look rather like dust of gold, abundance of its parts being broken and driven off; and it will seldom conduct above one strong shock. Perhaps this may be the reason: When there is not a perfect continuity in the circuit, the fire must leap over the vacancies: There is a certain distance which it is able to leap over according to its strength; if a number of small vacancies, though each be very minute, taken together exceed that distance, it cannot leap over them, and so the shock is prevented."

(a) A careful reading of this paragraph shows that Franklin had, at this early date, very clear ideas concerning the probable identity of electric discharges and lightning flashes. Here we find him actually constructing two kinds of movable charged conductors, that he believed correctly represented movable thunder-clouds, devising means by which these artificial clouds could readily move so that they could be brought within striking distance of earth-connected objects.

One of these movable clouds consists of a tube of pasteboard covered on the outside with gilt paper. By suspending this tube from the ceiling of the room by means of silk threads, he not only insulated the cloud, but also rendered it, within certain limits, readily movable, so as to permit it to approach earth-connected objects. Although this movable pasteboard cloud was only ten feet in length and one foot in diameter, yet its electric charge was capable of giving a sharp blow to the knuckle of a hand, approached sufficiently near to discharge it. He proved that such a cloud, when charged, was capable of being silently discharged by means of a needle point, held in the hands of a person standing on the floor of a room, when brought within a distance of twelve inches or so from the tube.

But while the needle point is thus capable of silently discharging the cloud, a blunt body, such as a smooth iron bolt, is unable to do so until brought much nearer to the tube, say within three inches instead of twelve inches. As soon as a blunt object is sufficiently near, the tube is disruptively discharged with a snap or crack. The phenomena to which Franklin calls especial attention in these experiments is the ability of the cloud to be silently discharged by the needle point, but that when the cloud is approached by a blunt object before the discharge takes place, an attraction occurs, whereby the cloud is moved towards the blunt object until the distance is sufficiently small to permit of its disruptive discharge. It is in this manner, he believes, that the real clouds in the sky approach the tops of tall objects on the earth until the distance is sufficiently small to permit the bolt to strike.

Another form of movable cloud was obtained by charging one of the scale pans of an ordinary balance. This experiment is practically the same as that of the pasteboard, except that during it, he showed the possibility of discharging the scale pan by means of a needle point placed on the floor of the room immediately below the balance, with its point directed upwards.

(b) "Now if the fire of electricity and lightning be the same." Franklin here acknowledges that an objection may fairly be made that the pasteboard cloud is puny when compared with the clouds that occur in thunder storms. In this connection however, he properly calls attention to the fact that, if the pasteboard cloud, with the limited area possessed by a cylinder of but one foot in diameter and ten feet in length, is capable of discharging across a spark gap of two or three inches, might not a cloud consisting of probably some 10,000 acres of electrified particles of moisture be able to strike the earth across a much greater gap. Moreover, if a needle point, approached to within a distance of say twelve inches of the pasteboard cloud, be capable of silently discharging it, might not the same thing be done with thunder clouds, and thus prevent their disastrous strokes to the earth.

(c. "I say, if these things are so, may not the knowledge of

this power of points be of use to mankind in preserving houses, churches, ships, etc., from strokes of lightning." Here is a clear statement of Franklin's great invention of the lightning rod,a matter that we shall discuss later on. The point to which I especially desire to call your attention is the fact that Franklin invented the lightning rod long before he actually drew electricity from the clouds.

(d) "To determine the question whether the clouds that contain lightning are electrified or not, I would propose an experiment to be tried, where it can be done conveniently." Remember that these words were written in 1749. To Franklin's philosophical mind, there did not appear to exist any reasonable doubt but that the clouds that contained lightning were electrified, so that his artificial cloud, consisting as it did of a movable gilded pasteboard tube, appeared to resemble an actual cloud, save only in two important respects: first, as regards its size; and second, as regards its distance from the surface of the earth, or from such a point as he could approach it sufficiently to draw from it some of its electrical charge. It was an easy matter to discharge his artificial cloud to the earth through the metallic punch, at a distance of two or three inches, but it was another thing to get sufficiently near an actual cloud as to successfully draw from it some of its charge. Franklin conceived the idea that, if he could climb to the top of a church steeple or tower, thereby coming that much nearer to the cloud, he could treat it as he did the electrified tube; but, unfortunately for Franklin, there were no tall towers or church steeples existing in Philadelphia at that time, which could serve his purpose.

Consequently, with the spirit of a true philosopher, he describes the experiment that he would like to have tried by others "Where it may be done conveniently." So he directs the construction of the sentry box represented in Fig. 6, large enough to hold an observer and an electrical stand; *i. e.*, a cake of wax. At the middle of this cake of wax, an iron rod passes by a bend out of the door, and so thirty or forty feet above the top of the box, thus getting that much nearer to the clouds. Franklin's idea was, and that it it was correct the use of this apparatus by others clearly showed, that

if a cloud should pass sufficiently near to the upper part of the rod, which was provided with a sharp point at the end, it would become electrified, so that sparks could be drawn from it, just as he did afterwards from his kite. Franklin expresses the opinion that the man would be exposed to no danger if he stood on the floor of his box, and occasionally brought near to the rod a loop of wire, the lower end of which was earthed by being fastened to the metallic leads of the building, he holding the other end by means of an insulating handle formed of wax. It was this suggestion, as we shall afterwards see, that Dalibard made use of in his drawing electricity from the sky.

(e) In the balance of this portion of the paper that we have quoted, Franklin cites some of the resemblances between lightning and electricity. The lightning has been known, he says, to strike people blind. He recalls an experiment he made with a pigeon, that was apparently killed by an electrical shock, but which was partially resuscitated, and died a few days afterwards. Also on an experiment he made with a pullet, which was afterwards resuscitated by artificial respiration, and was apparently perfectly blind. He, therefore, from this experiment, concluded that the pigeon had probably also been blinded by the shock, as it had refused food.

(f) Note here the ingenious method employed by Franklin to duplicate the effects of a lightning stroke that occurred during a thunder storm at Stretham, referred to by Mr. Miles. In this storm the lightning bolt stripped off all the paint that had covered a gilded moulding on the panel of a wainscoat, without, however, affecting the rest of the paint. Franklin conceived the idea of reproducing this effect by seeing what would happen is he sent a strong electrical discharge through some gilding on a book. Not having any paint at hand, he employs in its place a narrow strip of paper, pasted over the gilding. As soon as this had thoroughly dried, a discharge was sent through the gilding, with the result that the paper was torn off, from end to end, so violently that it was broken in several places. Indeed, in some places it took away a portion of the Turkey leather with which the book was bound.

(g) In the next paragraph, Franklin refers to some curious

results in the melting of metal by a process that he characterizes as cold fusion. Though his philosophy here is bad, his technique, that is, the method that he employs for melting metals by his so-called cold fusion, is excellent. It will be observed that in the method employed he obtained a continuous circuit of thin gold leaf between two plates of glass that were tightly bound together by silk thread, in such a manner as to prevent the breaking of the film by the accidental moving of the glass. The conditions were such as to permit the passage of a powerful Leyden jar discharge through this circuit by means of the two ends of gold leaf projected beyond the glass plate. Under these circumstances, the gold was deflagrated; *i. e.*, not only fused, but fused and volatilized by the great heat of the discharge; so that a series of metallic stains were produced on the glass, these stains being exactly duplicated to the minutest details on both pieces of glass that were in contact with the metal. Franklin corrected his erroneous idea concerning cold fusion at a later date. In order, however, to prevent confusion at this point we defer its discussion to another part of this article.

In this connection, Franklin refers to some experiments he had made in sending a discharge through the gilding on a book. He remarks that a careful examination of the book after the passage of a disruptive discharge showed that a single strong shock resulted in breaking the continuity of the gilding, so that, instead of remaining in the shape of a metallic leaf, it was shattered to metallic dust.

As is clearly indicated by the preceding experiments, Franklin had given considerable thought respecting the probable identity of a disruptive electric discharge and a lightning flash. It appears that he was not only in the habit of making notes containing descriptions of the experiments he had tried, but also of those which he desired to try. In these latter notes he generally placed the reasons he had for trying the experiments. It was from these notes that his letters were subsequently prepared.

There is an unfortunate absence of exact data in the case of many of Franklin's experiments. This is especially true as re-

gards his great experiment of drawing electricity from the sky. In a letter written to Dr. L, of Charlestown, South Carolina, dated May 18, 1755, he says:

"Your question, how I came first to think of proposing the experiment of drawing down the lightning, in order to ascertain its sameness with the electric fluid, I cannot answer better than by giving you an extract from the minutes I used to keep of the experiments I made, with memorandums of such as I purposed to make, the reasons for making them, and the observations that arose upon them, from which minutes my letters were afterwards drawn. By this extract you will see that the thought was not so much 'an out-of-the-way one,' but that it might have occurred to any electrician.

"'Nov. 7, 1749. Electrical fluid agrees with lightning in these 'particulars: 1. Giving light. 2. Colour of the light. 3. Crooked direc-'tion. 4. Swift motion. 5. Being conducted by metals. 6. Crack or noise 'in exploding. 7. Subsisting in water or ice. 8. Rending bodies it passes 'through. 9. Destroying animals. 10. Melting metals. 11. Firing in-'flammable substances. 12. Sulphureous smell. * * * The electric fluid 'it attracted by points. * * * We do not know whether this property is 'in lightning. * * * But since they agree in all the particulars wherein 'we can already compare them, is it not probable they agree likewise in 'this? * * * Let the experiment be made.'"

Franklin, apparently growing tired of waiting for a church steeple or tower to be erected in the City of Philadelphia, conceived the bold idea of reaching the higher regions of the atmosphere by means of a kite, and by this means actually succeeds in drawing the electricity from the clouds, and thus establishing the identity between the disruptive discharge and the lightning bolt.

In Vol. I, page 108, of the Complete Works in Philosophy, Politics and Morals of the late Benjamin Franklin, published in London in 1806, by Dr. Stuber, a Philadelphian, and intimate friend of Franklin, the following statement is made concerning this kite:

"While Franklin was waiting for the erection of a spire, it occurred to him that he might have more ready access to the region of clouds by means of a common kite. He prepared one by fastening two cross-sticks to a silk handkerchief, which would not suffer so much from the rain as paper. To the upright stick was affixed an iron point. The string was, as usual, of hemp, except the lower end, which was silk. Where the hempen string terminated, a key was fastened. With this apparatus, on the appearance of

a thunder-gust approaching, he went out into the common accompanied by his son, to whom alone he communicated his intentions, well knowing the ridicule which, too generally for the interest of science, awaits unsuccessful experiments in philosophy. He placed himself under a shed to avoid the rain. His kite was raised. A thunder cloud passed over it. No sign of electricity appeared. He almost despaired of success, when suddenly he observed the loose fibres of his string move toward an erect position. He now presented his knuckle to the key and received a strong spark. Repeated sparks were drawn from the key, the phial was charged, a shock, and all the experiments made which are usually performed with electricity."

As regards the construction of this kite, Franklin himself gives the following description in a letter to his friend Collinson, dated Philadelphia, October 19, 1753:

"As frequent mention is made in public papers from *Europe* of the success of the *Philadelphia* experiment for drawing the electric fire from clouds by means of pointed rods of iron erected on high buildings, &c., it may be agreeable to the curious to be informed that the same experiment has succeeded in *Philadelphia*, though made in a different and more easy manner, which is as follows:

"Make a small cross of two light strips of cedar, the arms so long as to reach to the four corners of a large thin silk handkerchief when extended; tie the corners of the handkerchief to the extremities of the cross, so you have the body of a kite; which being properly accommodated with a tail, loop, and string, will rise in the air, like those made of paper; but this being of silk, is fitted to bear the wet and wind of a thunder-gust without tearing. To the top of the upright stick of the cross is to be fixed a very sharp pointed wire, rising a foot or more above the wood. To the end of the twine, next the hand, is to be tied a silk ribbon, and where the silk and twine join, a key may be fastened. This kite is to be raised when a thunder gust appears to be coming on, and the person who holds the string must stand within a door or window, or under some cover, so that the silk ribbon may not be wet; and care must be taken that the twine does not touch the frame of the door or window. As soon as any of the thunder clouds come over the kite, the pointed wire will draw the electric fire from them, and the kite, with all the twine, will be electrified, and the loose filaments of the twine will stand out every way, and be attracted by an approaching finger. And when the rain has wet the kite and twine, so that it can conduct the electric fire freely, you will find it stream out plentifully from the key on the approach of your knuckle. At this key the phial may be charged; and from electric fire thus obtained, spirits may be kindled, and all the other electric experiments be performed, which are usually done by the help of a rubbed glass globe or tube, and thereby the sameness of the electric matter with that of lightning completely demonstrated."

It is not certain just at what portion of the City of Philadelphia Franklin flew his kite. In the opinion of some who have

studied this matter carefully, it was probably in the neighborhood of the high ground at about 18th and Spring Garden Streets, since this situation would most probably have afforded him a better exposure to the wind, and, at the same time, would have given him that seclusion which, for the time being, he desired. Franklin was evidently accustomed to walking over all the outskirts of the city which lay between the Delaware and the Schuylkill, especially in the portions near the latter river, for, he mentions in one of his letters experiments made in igniting sulphur by a wire laid across the Schuylkill River. Succeeding in raising his kite on the approach of a thunder storm at some place, near 18th and Spring Garden Streets, or somewhere in this neighborhood, he at last has the satisfaction of being able to draw from the key attached to the lower end of the kite string, sparks, which he recognizes at once as being similar to those produced by the electrical machine. In this manner was realized one of the grandest discoveries in the domain of physical science, and the actual identity of the lightning flash and electric discharges was at last demonstrated beyond any possible doubt.

It must not for a moment be supposed that, having in this manner succeeded in drawing electricity from the clouds, Franklin was willing to rest his great discovery. On the contrary, we find him making repeated experiments, obtaining electricity from the clouds under varying conditions. At a somewhat later date, he was able to draw electricity from a rod erected from the roof of a house, and with this apparatus we find him actually testing the character of the electric excitement that was to be found in charged thunder-clouds. Generally speaking, he found such clouds to possess a negative charge, but he also found that their charge was sometimes positive.

Although the following description of this original experiment, prepared shortly afterward, is not unlike the one given by Stuber, yet literature on the subject is so comparatively limited that I thought it advisable to annex it:

"Furnished with this apparatus, on the approach of a storm, he went out upon the commons near Philadelphia, accompanied by his son, to whom alone he communicated his intentions, well knowing the ridicule which

would have attended the report of such an attempt should it prove to be unsuccessful. Having raised the kite, he placed himself under a shed, that the ribbon by which it was held might be kept dry, as it would become a conductor of electricity when wetted by rain, and so fail to afford that protection for which it was provided. A cloud, apparently charged with thunder, soon passed directly over the kite. He observed the hempen cord; but no bristling of its fibres was apparent, such as was wont to take place when it was electrified. He presented his knuckle to the key, but not the smallest spark was perceptible. The agony of his expectation and suspense can be adequately felt by those only who have entered into the spirit of such experimental researches. After the lapse of some time he saw that the fibres of the cord near the key bristled, and stood on end. He presented his knuckle to the key, and received a strong, bright spark. It was lightning. The discovery was complete, and Franklin felt that he was immortal."

Probably one of the most curious circumstances connected with this phase of the early history of electric science is the difficulty in fixing an actual date when this memorable experiment was made by Franklin. It seems almost incredible that no one of the accounts of so important an experiment, that was at once heralded over the entire scientific world, should have failed to give the precise date at which it was made. In Stuber's account of this experiment, there is the same uncertainty, although we are here given a little more accurate information, viz.:"It was not until the summer of 1752 that Franklin was enabled to complete his grand and unparallelled discovery by experiment."

Priestley, in his "History of Electricity," (Vol. I, London, 1775), says: "This happened in June, 1752, a month after the electricians in France had verified the same theory, but before he had heard of anything they had done."

But in the meanwhile the memorable letter sent by Franklin to Collinson, containing a full account of his (Franklin's) numerous electrical experiments made at Philadelphia in 1749, but dated Philadelphia, July 29, 1750, and among them descriptions of his artificial clouds and his proposals to protect buildings by means of pointed conductors, was brought to the attention of the scientific world, and began to have its effect. Collinson recognized that this letter contained discoveries and inventions of more than ordinary value. Therefore, he brought it at once to the attention of the Royal Society, but the paper was received with actual derision. The members of

the Society were apparently unwilling to acknowledge that a provincial could make a discovery of such a nature at to be worthy their attention.

Collinson, provoked at the treatment his friend had thus received at the hands of the Royal Society, endeavored to obtain elsewhere the publication of this valuable paper. He offered it to Cave, the publisher of the Gentlemen's Magazine. While unwilling to permit Franklin's paper to appear as a part of his regular journal, yet Cave consented to print it as a separate publication. This was done in 1751. This publication, however, appears to have been received coldly in England, owing doubtless to the indifferent manner in which the paper was received by the Royal Society.

Fortunately, however, one of these publications of Franklin's paper was sent to Count de Buffon, at Paris. De Buffon, at once recognizing the very great value of the paper, took it to D'Alibard, a well-known French botanist, and requested him to translate it into French. Although this translation was far from being good, yet the paper attracted such attention throughout France that it had an enormous sale, creating, as it did, no little excitement in intellectual circles. The probability of Franklin's views as to the cause of lightning being correct, became a matter of general discussion, not only in scientific society, but throughout the Court of France. In this manner, Franklin's experiments and suggestions came to the knowledge of the King, who requested that these experiments be shown him. This was done, and greatly excited his interest.

Noting the great interest the King took in these experiments, three Frenchmen, *i. e.*, D'Alibard, M. de Lor, an instructor in Physics, and Count de Buffon, consulted together and came to the conclusion that none of the experiments made or suggested by Franklin would so interest the King as would the successful trying of Franklin's proposed experiment of drawing down lightning from the clouds by means of a pointed rod. Each of these gentlemen determined to try the experiment independently of the others, and all of them succeeded, D'Alibard on the 10th of May, De Lor on the 18th of May, and De Buffon on the 19th of May, 1752.

D'Alibard prepared for his experiment by erecting an iron rod, forty feet high, in a garden at Marly-la-Ville, eighteen miles from Paris. In accordance with Franklin's directions, this rod was insulated at its base, which rested on a table arranged within a small cabin, from the posts of which the rod was insulated by silken ropes.

When the first thunder storm to which this apparatus was subjected occurred, D'Alibard was not in the neighborhood. He had, however, placed a trustworthy soldier, named Corffier, in whom he had confidence, in charge of the apparatus, and had provided him with a brass wire, insulated by being mounted in a glass bottle for a handle, and had given him instructions to draw off any sparks from the rod should it become electrified. Some three days after the erection of the rod, while Corffier was on guard, a storm occurred, and Corffier was able to draw long and very noisy discharges from the insulated rod on the 10th of May. The dangerous appearances of these discharges so frightened the soldier that he sent for the village priest, one Raulet, under the full conviction that the marked disturbance, accompanied as it was with what he believed was a sulphurous odor, belonged to things of the lower world. The Priest, accompanied by many villagers, arrived before the storm had passed, and the Priest, not fearing the power of the Evil One, was willing to make experiments for himself by drawing sparks with a brass wire. He describes these experiments in a letter he sent to D'Alibard as follows: "I repeated this experiment at least six times in about four minutes, in the presence of many persons, and every time the experiment lasted the space of a pater and an eve." At one time he accidentally touched the rod, and got a very severe shock.

Before he left the place where the experiment was made the Priest sent the letter above referred to, to D'Alibard by Corffier. D'Alibard at once prepared a memoir on the subject, which he communicated to the French Academy of Sciences three days later; *i. e.*, May 13.

The following translation from this paper will show that D'Alibard did not hesitate to give to Franklin the credit of this experiment:

"From all the experiments and observations contained in the present paper, and more especially from the recent experiment made at Marly-la-

Ville, it is shown beyond doubt that the matter made of lightning is the same as that of electricity; it has become a reality, and I believe that the more we realize what he (Franklin) has published on electricity, the more will we acknowledge the great debt that physical science owes to him."

The relations existing between D'Alibard and Franklin were of the most cordial character. In a letter from D'Alibard to Franklin, dated Paris, March 31, 1752, D'Alibard says:

"We are all waiting with the greatest eagerness to hear from you. I beg that you will let me have letters as soon and often as possible. Your name is venerated in this country as it deserves to be. There are but few electricians, like the Abbe Nollet, whose jealousy is excited by the honor your discoveries have obtained.

"With great respect and esteem I am, &c.,

DALIBARD."

But that restless kind of philosopher, the so-called higher critic, who, in so many cases, unable to do anything original themselves, rest content with calling into question the work of better men, have sought to detract from the merit of Franklin's great discovery by the statement that even if Franklin did draw electricity from the clouds, which some of them have been foolish enough to doubt, yet in reality one De Romas, a French barrister, residing in Nerac, some seventy-five miles south of Bordeaux, antedated Franklin, as some say, in the conception of the kite; as others say, in the date at which it was employed for drawing lightning from the air; and as still others say, in both of these respects.

Without going any further into this subject, it suffices to say that Franklin's kite was successfully employed, as already mentioned, some time in June, 1752, while the kite of De Romas was not raised until the 14th of May, 1753. At this date his experiment was unsuccessful, but at a later date, June 7, 1753, having made the string of his kite a better conductor by wrapping around the outside of its entire length a fine copper wire, he was successful in his attempt.

Priestly gives the following description of his kite in Vol. I of his book on Electricity already referred to:

"The greatest quantity of electricity that was ever brought from the clouds, by any apparatus prepared for that purpose, was by Mr. De Romas, assessor to the presideal of Nerac. This gentleman was the first who made use of a wire interwoven in the hempen cord of an electrical kite, which he

made seven feet and a half high, and three feet wide, so as to have eighteen square feet of surface. This cord was found to conduct the electricity of the clouds more powerfully than a hempen cord would do, even though it was wetted; and, being terminated by a cord of dry silk, it enabled the observer (by a proper management of his apparatus) to make whatever experiments he thought proper, without danger to himself.

"By the help of this kite, on the 7th of June, 1753, about one in the afternoon, when it was raised 550 feet from the ground and had taken 780 feet of string, making an angle of near forty-five degrees with the horizon; he drew sparks from his conductor three inches long and a quarter of an inch thick, the snapping of which was heard about 200 paces. Whilst he was taking these sparks, he felt, as it were, a cob-web on his face, though he was above three feet from the string of the kite; after which he did not think it safe to stand so near, and called aloud to all the company to retire, as did himself about two feet."

"Thinking himself now secure enough, and not being incommoded by any body very near him, he took notice of what passed among the clouds which were immediately over the kite; but could perceive no lightning either there or anywhere else, nor scarce the least noise of thunder, and there was no rain at all. The wind was West, and pretty strong, which raised the kite 100 feet higher, at least than in the other experiments.

"Afterwards, casting his eyes on the tin tube, which was fastened to the string of the kite, and about three feet from the ground, he saw three straws, one of which was about one foot long, a second four or five inches, and performing a circular dance, like puppets, under the tin tube, without touching one another.

"This little spectacle, which much delighted several of the company, lasted about a quarter of an hour; after which, some drops of rain falling, he again perceived the sensation of the cob-web on his face, and at the same time heard a continual rustling noise, like that of a small forge bellows. This was a farther warning of the increase of electricity; and from the first instant that Mr. De Romas perceived the dancing straws, he thought it not advisable to take any more sparks, even with all his precautions; and he again entreated the company to spread themselves to a still greater distance.

"Immediately after this came on the last act of the entertainment, which De Romas acknowledged made him tremble. The longest straw was attracted by the tin tube, upon which followed three explosions, the noise of which greatly resembled that of thunder. Some of the company compared it to the explosion of rockets, and others to the violent crashing of large earthen jars against a pavement. It is certain that it was heard into the heart of the city, notwithstanding the various noises there.

"The fire that was seen at the instant of the explosion had the shape of a spindle eight inches long and five lines in diameter. But the most astonishing and diverting circumstances was produced by the straw, which had occasioned the explosion, following the string of the kite. Some of the company saw it at forty-five or fifty fathoms distance, attracted and repelled al-

ternately, with this remarkable circumstance, that every time it was attracted by the string flashes of the fire were seen, and cracks were heard, though not so loud as at the time of the former explosion.

"It is remarkable, that, from the time of the explosion to the end of the experiment, no lightning at all was seen, nor scarce any thunder heard. A smell of sulphur was perceived, much like that of the luminous electric effluvia issuing out of the end of an electrified bar of metal. Round the string appeared a luminous cylinder of light, three or four inches in diameter: and this being in the day-time Mr. De Romas did not question but that, if it had been in the night, that electric atmosphere would have appeared to be four or five feet in diameter. Lastly, after experiments were over, a hole was discovered in the ground, perpendicularly under the tin tube, an inch deep, and half an inch wide, which was probably made by the large flashes that accompanied the explosions.

"An end was put to these remarkable experiments by the falling of the kite, the wind being shifted into the East, and rain mixed with hail coming on in great plenty. Whilst the kite was falling, the string came foul of a penthouse; and it was no sooner disengaged, than the person who held it felt such a stroke in his hands, and such a commotion through his whole body, as obliged him instantly to let it go; and the string, falling on the feet of some other persons, gave them a shock also, though much more tolerable."

The extraordinary interest awakened by the successful drawing of electricity from the clouds caused these experiments to be repeated in different parts of the world, with apparatus of various types. To a great extent, this apparatus consisted of rods extending upwards into the air. Some of this apparatus was exceedingly simple and crude in its construction, as may be seen from the following description given by Priestley:

"The most accurate experiments made with these imperfect instruments, were those of Mr. Monnier. He was convinced that the high situation in which the bar of iron had commonly been placed was not absolutely necessary for this purpose: for he observed a common speaking-trumpet, suspended upon silk five or six feet from the ground, to exhibit very evident signs of electricity. He also found that a man placed upon cakes of rosin, and holding in his hand a wooden pole, about eighteen feet long, about which an iron wire was twisted, was so well electrified when it thundered, that very lively sparks were drawn from him; and that another man, standing upon non-electrics, in the middle of a garden, and only holding up one of his hands in the air, attracted, with the other hand, shavings of wood which were held to him."

An Englishman named Mr. Canton, succeeded in drawing an electric discharge from the clouds on the 20th of July, 1752, as will be seen from a letter written by him, dated Spital-Square, July 21, 1752:

"I had yesterday, about five in the afternoon, an opportunity of trying "Mr. Franklin's experiment of extracting the electrical fire from the "clouds; and succeeded, by means of a tin tube, between three and four "feet in length, fixed to the top of a glass one, of about eighteen inches. To "the upper end of the tin tube, which was not so high as a stack of chimnies "on the same house, I fastened three needles with some wire; and to the "lower end was folded a tin cover to keep the rain from the glass tube, "which set upright in a block of wood. I attended this apparatus as soon "after the thunder began as possible, but did not find it in the least electri- "fied, till between the third and fourth clap; when applying my knuckle to "the edge of the cover, I felt and heard an electrical spark; and approach- "ing it a second time, I received the spark at the distance of about half an "inch, and saw it distinctly. This I repeated four or five times in the space "of a minute; but the sparks grew weaker and weaker; and in less than two "minutes the tin tube did not appear to be electrified at all. The rain con- "tinued during the thunder, but was considerably abated at the time of mak- "ing the experiment."

At a somewhat later date, August 12, 1752, another Englishman, a Mr. Wilson, succeeded, by the use of an exceedingly crude apparatus, in drawing electricity from the clouds. The following description of Wilson's apparatus experiment is from a letter of Mr. Watson to the Royal Society:

"Mr. Wilson likewise of the Society, to whom we are much obliged for the trouble he has taken in these pursuits, had an opportunity of verifying Mr. Franklin's hypothesis. He informed me, by a letter from near Chelmsford in Essex, dated August 12, 1752, that, on that day about noon, he perceived several electrical snaps, during, or rather at the end of a thunder storm, from no other apparatus than an iron curtain rod, one end of which he put into the neck of a glass phial, and held this phial in his hand. To the other end of the iron he fastened three needles with some silk. This phial, supporting the rod, he held in one hand, and drew snaps from the rod with a finger of his other. This experiment was not made upon any eminence, but in the garden of a gentleman, at whose house he then was."

Shortly after his successful experiment with the electrical kite, Franklin erected a rod on his house, of which he gives the following description:

In September, 1752, I erected an iron rod to draw the lightning down into my house, in order to make some experiments on it, with two bells to give notice when the rod should be electrifi'd: A contrivance obvious to every electrician.

"I found the bells rang sometimes when there was no lightning or thunder, but only a dark cloud over the rod; that sometimes after a flash of

lightning they would suddenly stop; and, at other times, when they had not rang before, they would, after a flash, suddenly begin to ring; that the electricity was sometimes very faint, so that when a small spark was obtain'd, another could not be got for sometime after; at other times the sparks would follow extremely quick, and once I had a continual stream from bell to bell, the size of a crow-quill: Even during the same gust, there were considerable variations."

In a letter dated April 18th, 1754, to Collinson, Franklin describes some of the results obtained by this apparatus:

"Since September last, having been abroad on two long journeys, and otherwise much engag'd, I have made but few observations on the *positive* and *negative* state of electricity in the clouds. But Mr. Kinnersley kept his rod and bells in good order, and has made many.

"Once this winter the bells rang a long time, during a fall of snow, tho' no thunder was heard, or lightning seen. Sometimes the flashes and cracks of the electric matter between bell and bell were so large and loud as to be heard all over the house: but by all his observations, the clouds were constantly in a negative state, till about six weeks ago, when he found them once to change in a few minutes from the negative to the positive. About a fortnight after that he made another observation of the same kind; and last Monday afternoon, the wind blowing hard at S. E. and veering round to N. E. with many thick driving clouds, there were five or six successive changes from negative to positive, and from positive to negative, the bells stopping a minute or two between every change. Besides the methods mentioned in my paper of *September* last, of discovering the electrical state of the clouds the following may be us'd: When your bells are ringing, pass a rubb'd tube by the edge of the bell, connected with your pointed rod: if the cloud is then in a negative state, it will continue, and perhaps be quicker. Or, suspend a very small cork-ball by a fine silk thread, so that it may hang close to the edge of the rod-bell: then whenever the bell is electrified, whether positively or negatively, the little ball will be repell'd, and continue at some distance from the bell. Have ready a round-headed glass stopper of a decanter, rub it on your side till it is electrified, then present it to the cork-ball. If the electricity in the ball is positive, it will be repell'd from the glass stopper as well as from the bell. If negative, it will fly to the stopper."

It seldom falls to the lot of any scientific man, no matter how great his ability, that he is able to follow a road so absolutely new that it has never been traversed before. This unquestionably was the case with Franklin in his grand discovery of drawing the lightning from the sky, thus robbing Jove of his thunder-bolts.

Very long, indeed, before Franklin's time, the general resemblance between lightning and electrical discharges had been

noted. Indeed, some go so far as to say that before lightning had been known to be a form of electricity, some bold investigators had actually succeeded in purposely drawing it to the earth. The fabled Prometheus, who is credited with having stolen the sacred fire from Heaven, is claimed by some as being in reality Franklin's predecessor; that the sacred fire was lightning, purposely drawn down from the clouds by Prometheus. There is, of course, no actual evidence of this being the case. It would seem to me that the fable of Prometheus was intended to immortalize the act of that master mind who first taught the human race the art of cooking, thus increasing the number of food products that could be safely employed after the material had been subjected to the action of heat.

Another ancient who has been brought forward as a predecessor of Franklin was one of the earlier Romans, Numa Pompilius, who, it is claimed, on several occasions drew down the sacred fire with entire safety. Not so fortunate, however, was Tillius Hostilius, who, it is claimed, having read some notes left by Numa respecting the sacred art of worshipping Jupiter, rashly attempted to repeat the worship, but, departing from the rules of the sacred rite, was struck dead by a bolt from the irate Jupiter.

Ovid thus refers to one of the Kings of Alba, who was struck dead by a bolt from Heaven while performing a similar ceremony:

"Fulmineo periit imitator fulminis ictu."
("In imitating thunder, the thunderer perished.")

But the prior claimants for the honor of antedating Franklin in his great discovery are not limited to these vague beliefs. There are a number of unquestioned printed records in which, at least the close resemblance between electrical discharges and lightning flashes are referred to. Some of these are as follows:

In 1705, Hawkesbee, while experimenting on the luminous phenomena produced by permitting mercury to fall from the top of a glass tube in which a partial vacuum is maintained, noted that there were thus "Produced flashes resembling lightning;" and at a later date, the same hilosopher, noting the luminous effects produced by the friction of a woolen cloth against a glass tube, said that he "Observed light to

break from the agitated glass in as strange a form as lightning." Hawkesbee did not know that the luminous effects were in reality electric discharges, so that this can scarcely be regarded as an anticipation of Franklin's work.

In the same year, however, Gray calls attention, in the Philosophical Transactions, to the resemblances that exist between the effects of electric discharges and those of lightning and thunder.

In 1708, Wall, in the Philosophical Transactions, calls attention to the resemblance between the crackling and the flash accompanying the rubbing of amber, and thunder and lightning, remarking: "This light and crackling seem in some degree to represent thunder and lightning."

At a much later date; *i. e.*, in 1748, the Abbe Nollet, in his "Lessons in Physics," says:

"If any one should undertake to prove, as a clear consequence of the phenomenon, that thunder is in the hands of nature what Electricity is in ours * * * that those wonders which we dispose at our pleasure are only imitations on a small scale of those grand effects which terrify us, and that both depend on the same mechanical agents, if it were made manifest that a cloud prepared by the effects of the wind, by heat, by a mixture of exhalations, etc., is in relation to a terrestrial object what an electrified body is in relation to a body near it not electrified, I confess that this idea, well supported, would please me much; and to support it how numerous and specious are the reasons which present themselves to a mind conversant with Electricity. The universality of the electric matter, the readiness of its actions, its instrumentality and its activity in giving fire to ohter bodies, its property of striking bodies externally and internally, even to their smallest parts (the remarkable example we have of this effect even in the Leyden-jar experiment, the idea which we might truly adopt in supposing a greater degree of electric power), all these points of analogy which I have been for some time meditating, begin to make me believe that one might, by taking electricity for the model, form to one's self in regard to thunder and lightning more perfect and more probable ideas than hitherto proposed."

As will be seen, however, this suggestion is general, and does not appear to have ever been carried out by Nollet, nor can it for a moment properly be regarded as competing with the publication of Franklin before referred to, coupled, as Franklin's paper was, with a clear description of the manner in which a mimic lightning cloud discharged a bolt to neighboring ob-

jects, together with full directions as to how such a discharge might be avoided by the use of a suitably constructed pointed rod.

The following extracts from a letter written to Mr. Collinson give an account of Franklin's hypothesis for explaining the phenomena of thunder-gusts. This letter appears to have been written some time between April 29th, 1749, and July 29th, 1750. As the paper is a long one, I will only give extracts from it. The first portion of the paper refers to the manner in which electricity is capable of being produced by the friction of air against water.

"Observations and Suppositions, towards forming a new Hypothesis, for explaining the several Phenomena of Thunder-Gusts:

"9. The ocean is a compound of water, a non-electric, and salt an electric per se.

"10. When there is a friction among the parts near its surface the electrical fire is collected from parts below. It is then plainly visible in the night; it appears at the stern and in the wake of every sailing vessel; every dash of an oar shews it, and every surf and spray: In storms the whole sea seems on fire. * * * The detach'd particles of water then repelled from the electrified surface, continually carry off the fire as it is collected; they rise and form clouds, and those clouds are highly electrified, and retain the fire till they have an opportunity of communicating it.

"11. The particles of water rising in vapours, attach themselves to particles of air."

* * * * * * *

"26. Hence clouds formed by vapours raised from fresh waters within land, from growing vegetables, moist earth, &c., more speedily and easily deposite their water, having but little electrical fire to repel and keep the particles separate. So that the greatest part of the water raised from the land to the sea are dry; there being little use for rain on the sea, and to rob the land of its moisture, in order to rain on the sea, would not appear reasonable.

"27. But clouds formed by vapours raised from the sea, having both fires, and paricularly a great quantity of the electrical, support their water strongly, raise it high, and being moved by winds, may bring it over the middle of the broadest continent from the middle of the widest ocean.

"28. How these ocean clouds, strongly supporting their water, are made to deposite it on the land where it is want'd is next to be considered.

"29. If they are driven by winds against mountains, those mountains being less electrified attract them, and on contact take away their electrical

fire (and being cold, the common fire also;) hence the particles close towards the mountains and towards each other. If the air was not much loaded, it only falls in dews on the mountain tops and sides, forms springs, and descends to the vales in rivulets, which united, make larger streams and rivers. If much loaded, the electrical fire is at once taken from the whole cloud; and, in leaving it, flashes brightly and cracks loudly; the particles instantly coalescing for want of that fire, and falling in a heavy shower.

"30. When a ridge of mountains thus dams the clouds, and draws the electrical fire from the cloud first approaching it; that which next follows, when it comes near the first cloud, now deprived of its fire, flashes into it, and begins to deposite its own water; the first cloud again flashing into the mountains; the third approaching cloud, and all the succeeding ones, acting in the same manner as far back as they extend, which may be over many hundred miles of country.

"31. Hence the continual storms of rain, thunder, and lightning on the east side of the *Andes*, which running north and south, and being vastly high, intercept all the clouds brought against them from the *Atlantic* ocean by the trade wisds, and oblige them to deposit their waters, by which the vast rivers *Amazons*, *La Plata*, and *Oroonoko* are formed, which return the water into the same sea, after having fertilized a country of very great extent.

"32. If a country be plain, having no mountains to intercept the electrified clouds, yet it is not without means to make them deposite their water. For if an electrified cloud coming from the sea, meets in the air a cloud raised from the land, and therefore not electrified; the first will flash its fire into the latter, and thereby both clouds shall be made suddenly to deposite water.

"33. The electrified particles of the first cloud close when they lose their fire, the particles of the other cloud close in receiving it: in both, they have thereby an opportunity of coalescing into drops. * * * The concussion or jerk given to the air, contributes also to shake down the water, not only from those two clouds, but from others near them. Hence the sudden fall of rain immediately after flashes of lightning.

* * * * * * *

"35. Thus when sea and land clouds would pass at too great a distance from the flash, they are attracted towards each other till within that distance; for the sphere of electrical attraction is far beyond the distance of flashing.

"36. When a great number of clouds from the sea meet a number of clouds raised from the land, the electrical flashes appear to strike in different parts; and as the clouds are jostled and mixed by the winds, or brought near by the electrical attraction, then continue to give and receive flash after flash, till the electrical fire is equally diffused."

* * * * * * *

"40. When the air, with its vapours raised from the ocean between the tropics, comes to descend in the polar regions, and to be in contact with the vapours arising there, the electrical fire they brought begins to be communicated, and is seen in clear nights, being first visible where 'tis first in

motion, that is, where the contact begins, or in most northern part; from thence the streams of light seem to shoot southerly, even up the zenith of northern countries. But tho' the lights seem to shoot from the north southerly, the progress of the fire is really from the south northerly, its motion beginning in the north being the reason that 'tis there first seen.

"For the electrical fire is never visible but when in motion, and leaping from body to body, or from particle to particle thro' the air. When it passes thro' dense bodies 'tis unseen. When a wire makes part of the circle, in the explosion of the electrical phial, the fire, though in great quantity, passes in the wire invisibly: but in passing along a chain, it becomes visible as it leaps from link to link. In passing along leaf gilding 'tis visible; for the leaf-gold is full of holes; hold a leaf to the light and it appears like a net, and the fire is seen in its leaping over the vacancies. * * * And as when a long canal filled with still water is opened at one end, in order to be discharged, the motion of the water begins first near the opened end, and proceeds towards the close end, tho' the water itself moves from the close towards the open end: so the electrical fire discharged into the polar regions, perhaps from a thousand leagues length of vaporised air, appears first where 'tis first in motion, *i.e.*, in the most northern part, and the appearance proceeds southward, tho' the fire really moves northward. This is supposed to account for the *Aurora Borealis*.

"41. When there is great heat on the land, in a particular region (the sun having shone on it perhaps several days, while the surrounding countries have been screen'd by clouds) the lower air is rarified and rises, the cooler denser air above descends; the clouds in that air meet from all sides, and join over the heated place; and if some are electrified, others not, lightning and thunder succeed, and showers fall. Hence thunder-gusts after heats, and cool air after gusts; the water and the clouds that bring it, coming from a higher and therefore a cooler region.

"42. An electrical spark, drawn from an irregular body at some distance is scarce ever straight, but shows crooked and waving in the air. So do the flashes of lightning; the clouds being very irregular bodies.

"43. As electrified clouds pass over a country, high hills and high trees lofty towers, spires, masts of ships, chimneys, &c., as so many prominencies and points, draw the electrical fire, and the whole cloud discharges there."

It is interesting to note that Franklin's theory of thunder-gusts as contained in the above quotation, was published before he had actually drawn electricity from the clouds. This theory was, consequently, crude in many respects. Nevertheless, it is surprising how great an insight into the true theory of the thunder storm Franklin seemed to have obtained. This will be seen from the following general statements contained in this remarkable paper:

(1) He traces thunder-gusts to their true source; *i. e.*, the formation of clouds by vapors rising from the ocean.

(2) He points out that the most marked effects of lightning are produced when charged clouds are attracted to mountains or other objects on the earth; when, losing their electricity, the particles of water that were prevented from condensing by reason of the repulsion produced by that charge, fall to the ground. Here he appears to have lost sight of the fact that the loss of the charge follows the condensation rather than precedes it. This general truth he appears to have realized at a later period.

(3) That oppositely-charged clouds are capable of discharging into each other when they approach sufficiently near.

(4) That the frequent thunder storms which occur on the eastern plateau of the Andes are due to the discharge of the clouds on their coming in contact with the slopes of the mountains.

But Franklin goes further than this, and ascribes the cause of the aurora borealis to the effects of electrical discharges in regions where the discharges are no longer disruptive, as in the case of lightning, but take the form of quiet discharges.

It will be seen from an examination of paragraphs 9, 10 and 11, as given in the first part of the quotation, that while Franklin points out at least one of the ways in which the vapor obtains its electrical charge; *i. e.*, by the friction between the air and the surface of the ocean, he is in error in believing that the glow of light which is frequently distinctly visible during dark nights at the bow and in the wake of a sailing vessel, is an evidence of the presence of such an electrical charge, since, as it is now known, this glow is due to phosphorescence produced in an entirely different manner. At a later date; *i. e.*, January, 1752, in a letter to James Bowdoin, dated Philadelphia, January 24, 1752, and read before the Royal Society, May 27, 1756, he refers to this matter as follows:

"My supposition, that the sea might possibly be the grand source of lightning, arose from the common observation of its luminous appearance in the night, on the least motion; an appearance never observed in fresh water. Then I knew that the electric fluid may be pumped up out of the earth, by the friction of a glass globe, on a non-electric cushion; and that notwithstanding the surprising activity and swiftness of that fluid, and the non-electric communication between all parts of the cushion and the earth,

yet quantities would be snatched up by the revolving surface of the globe, thrown on the prime conductor, and dissipated in air. How this was done, and why that subtile, active spirit did not immediately return again from the globe into some part or other of the cushion, and so into the earth, was difficult to conceive; but, whether from its being opposed by a current setting upwards to the cushion, or from whatever other cause, that it did not so return was an evident fact. Then I considered the separate particles of water as so many hard spherules, capable of touching the salt only in points and imagined a particle of salt could therefore no more be wet by a particle of water, than a globe by a cushion; that there might therefore be such a friction between these original constituent particles of salt water, as in at sea of globes and cushions; that each particle of water on the surface might obtain from the common mass, some particles of the universal diffused, much finer, and more subtile electric fluid, and, forming to itself an atmosphere of those particles, be repelled from the then generally electrified surface of the sea, and fly away with them into the air. I thought, too, that possibly the great mixture of particles electric *per se*, in the ocean water might, in some degree, impede the swift motion and dissipation of the electric fluid through it to the shores, &c. But, having since found, that salt in the water of an electric phial does not lessen the shock; and having endeavored in vain to produce that luminous appearance from mixture of salt and water agitated; and observed, that even the sea-water will not produce it after some hours standing in a bottle; I suspect it to proceed from some principle yet unknown to us (which I would gladly make some experiments to discover, if I lived near the sea), and I grow more doubtful of my supposition, and more ready to allow weight to that objection (drawn from the activity of the electrical fluid, and the readiness of water to conduct), which you have indeed stated with great strength and clearness.

"In the meantime, before we part with this hypothesis, let us think what to substitute in its place. I have sometimes queried, whether the friction of the air, an electric *per se*, in violent winds, among trees, and against the surface of the earth, might not pump up, as so many glass globes, quantities of the electrical fluid, which the rising vapors might receive from the air, and retain in the clouds they form; on which I should be glad to have your sentiments. An ingenious friend of mine supposes the land clouds more likely to be electrified than the sea clouds. I send his letter for your perusal, which please return to me."

But paragraph 41, of the quotation, entitled Observations and Suppositions towards forming a new Hypothesis for Explaining the several Phenomena of Thunder-Gusts, is most worthy of notice in pointing out the cause of thunder-gusts. Here Franklin refers to any highly-heated area on the surface of the earth as the source from which the thunder-gust starts or has its origin. "When there is great heat on the land in a particular region (the sun having shone on it perhaps several

days, while the surrounding countries have been screen'd by clouds), the lower air is rarefied and rises, the cooler, denser air above descends; the clouds in that air meet from all sides and join over the heated place; and if some are electrified, others not, lightning and thunder descends, and showers fall; hence thunder-gusts after heats, and cool air after gusts, the water, and the clouds that bring it, coming from the higher, and therefore a cooler, region."

Franklin's idea that the electricity of the thunder cloud comes from the vapors that rise from the waters of the ocean was in accord with views that have been set forth after his time. Volta, for example, at a later date, was, perhaps, the first to assert that the free electricity of the air was due to the evaporation of water. Volta's idea was that evaporation alone, unattended by any wind or friction, could produce an electrical charge. These two statements therefore differed from each other in the fact that Franklin apparently regarded the cause of the charge to be due to the friction of the air against the particles of water, while Volta recognized that the mere molecular friction, such as attended the tearing apart of the molecules of the liquid water so as to permit them to vaporize, was also a cause of the charge.

Pouillet made the assertion that the evaporation of ocean water, in which, as is well known, a large percentage of common salt exists in solution, produced the most marked electrification; that under such circumstances the vapor was positively charged, while the vessel containing the water was negatively charged.

It is interesting to note in this connection a modern theory of atmospheric electricity proposed by Prof. Oliver Lodge, who has given considerable attention to these phenomena. Lodge questions whether it is probable that the electricity of the atmosphere is obtained by the friction of air against water, although he thinks it possible that a spray of mist driven by a storm wind against the earth's surface, may be able to produce electric charges. He suggests that since, as is well known, all thunder storms are attended by severe atmospheric disturbances, in which a rotary or whirling motion of the wind exists, that if it be acknowl-

edged that in thunder-gusts the axis of this rotary motion is horizontal, there would be produced in this manner a species of huge natural cylindrical frictional machine, with the earth as the rubber, and the upper conducting regions of the atmosphere as the prime conductor; that the air electrified by friction against the earth carries the charges so produced into the upper regions of the air, into which it discharges them.

Before passing from theory to facts, it will be interesting to review some of the attendant phenomena of thunder storms.

As is well known, thunder storms are generally divided into three classes; *i. e.*,—

(1.) Cyclonis Thunder Storms.
(2.) Heat Thunder Storms.
(3.) Winter Thunder Storms.

The cyclonic thunder storms attend areas of low barometer, and have a progressive motion, similar to that of cyclones. Under certain circumstances these storms produce tornadoes.

Heat thunder storms are those that are produced by the local heating of the lower air. A quiet day, when the air is filled with moisture, is favorable for the formation of storms of this character. They require for their production a sufficient heating of the air to carry it by means of strong ascending currents into the higher regions. It was mainly storms of this character that were studied by Franklin.

Winter thunder storms occur more frequently at night and in the higher latitudes. These storms are more frequent near the coasts of the continents than in the interior.

As is well known a thunder storm is characterized by a rotary motion of the atmosphere, with a progressive motion in which the area around which the air rotates moves bodily over the surface of the earth. Thunder storms only occur when there is an unusual quantity of moisture in the air. Consequently, they are generally accompanied by rainfall. The following description, condensed from Davis, gives an excellent idea of the different phenomena of the storm. In the temperate latitudes of the earth the beginning of the storm is heralded by hot day, of a fore-running layer of fleecy, feathery clouds, known as cirro-status clouds, that are arranged in horizontal

bands or layers in the higher regions of the atmosphere. The forward edge of this layer is thin, fibrous and hazy in appearance. As the cloud advances it grows thicker at its opposite end, from which ragged festoons of clouds slowly descend and dissolve from its lower surface as the great rain-bearing cloud mass approaches. The fore-running cloud may at times be from ten to fifty miles in advance of the approaching rain cloud. The air, which is oppressively hot before the storm, grows slightly cooler as the fore-running cloud hides the sun. Thunder heads, or lurid rounded dark clouds, can generally be seen rising in the west an hour or so before the fore-running sheet of clouds. Distant thunder is heard as these clouds approach, when below their level base, b, Fig. 7, a gray rain curtain, r, is to be seen, trailing over the ground and hiding all objects behind it. Small detached clouds, d, frequently form in front of the main cloud mass, rapidly increasing in size, and finally merging with the

Fig. 7. Phenomena of approaching thunder gust. (Davis)

storm cloud, which, moving more rapidly towards the east, at length overtakes them. A ragged squall cloud, s, light gray in color, rolls beneath the dark mass of clouds, somewhat back of its forward edge. The mass of storm cloud advances broadside with a velocity of twenty to fifty miles an hour. The short-lived outrushing wind squall, g, carrying with it clouds of dust, moves below the clouds and in front of the rain. A marked decrease in temperature occurs during the storm, this decrease frequently being from ten to twenty degrees in less than half an hour. The first falling drops of rain are large, rapidly changing, however, to a heavy downpour, that is sometimes accompanied by hail. The moisture in the air increases, vivid lightning flashes occur, with loud thunder, and, as the storm center comes more nearly overhead, the lightning flashes and thunder succeed each other more rapidly. The dark sheet in front of the storm grows less marked, and, as the center passes over, the lightning flashes become less frequent, until the storm

passes, the rain ceases, the clouds break in the west, blue sky appears, the air grows cooler, dryer and clearer.

In continuation of Franklin's theory of thunder storms and lightning generally, the following letter, written to Collinson from Philadelphia, September, 1753, and consequently after he had drawn the electricity from the clouds, gives an account of some experiments he made in order to determine whether clouds are electrified positively or negatively:

"In the winter following I conceived an experiment, to try whether the clouds were electrifi'd positively or negatively; but my pointed rod, with its apparatus, becoming out of order, I did not refit it till towards the spring when I expected the warm weather would bring on more frequent thunder-clouds.

"The experiment was this: To take two phials; charge one of them with lightning from the iron rod, and give the other an equal charge by the electric glass globe, thro' the prime conductor: When charg'd to place them on a table within three or four inches of each other, a small cork ball being suspended by a fine silk thread from the ceiling, so as it might play between the wires. If both bottles then were electrified positively, the ball being attracted and repelled by one, must be also repell'd by the other. If the one positively, and the other negatively; then the ball would be attracted and repelled—alternately by each, and continue to play between them as long as any considerable charge remained.

"Being very intent on making this experiment, it was no small mortification to me, that I happened to be abroad during two of the greatest thunder-storms we had early in the Spring, and tho' I had given orders in my family, that if the bells rang when I was from home, they should catch some of the lightning for me in electrical phials, and they did so, yet it was mostly dissipated before my return, and in some of the other gusts, the quantity of lightning I was able to obtain was so small, and the charge so weak, that I could not satisfy myself: Yet I sometimes saw what heighten'd my suspicions, and inflamed my curiosity.

"At last, on the 12th of April, 1753, there being a smart gust of some continuance, I charged the phial pretty well with lightning, and the other equally, as near as I could judge, with electricity from my glass globe; and, having placed them properly, I beheld, with great surprise and pleasure, the cork ball played briskly between them; and was convinced that one bottle was electrised negatively.

"I repeated this experiment several times during the gust, and in eight successive gusts, always with the same success: and being of opinion (for reasons I formerly gave in my letter to Mr. Kinnersly, since printed in London) that the glass globe electrises positively, I concluded that the clouds are always electrised negatively, or have always in them less than their natural quantity of the electric fluid.

"Yet notwithstanding so many experiments, it seems I concluded too

soon; for at last, June 6th, in a gust which continued from five o'clock, P. M to seven, I met with one cloud that was electrised positively, tho' several that pass'd over my rod before, during the same gust, were in the negative state. This was thus discovered.

"I had another concurring experiment, which I often repeated, to prove the negative state of the clouds, viz. While the bells were ringing, I took the phial charged from the glass globe, and applied its wire to the erected rod, considering, that if the clouds were electrised positively, the rod, which received its electricity from them, must be so too; and then the additional positive electricity of the phial would make the bells ring faster. * * * * But if the clouds were in a negative state, they must exhaust the electric fluid from the rod, and bring that into the same negative state with themselves, and then the wire of a positively charg'd phial, supplying the rod with what it wanted, (which it was obliged otherwise to draw from the earth by means of the pendulous brass ball playing between the two bells) the ringing would cease until the bottle was discharg'd.

"In this manner I quite discharged into the rod several phials that were charged from the glass globe, the electric fluid streaming from the wire to the rod, 'till the wire would receive no spark from the finger; and during this supply to the rod from the phial the bells stopt ringing; but by continuing the application of the phial wire to the rod, I exhausted the natural quantity from the inside surface of the same phials, or, as I call it, charged them negatively.

"At length, while I was charging a phial by my glass globe, to repeat this experiment, my bells, of themselves, stopt ringing, and, after some pause, began to ring again. * * * But now, when I approached the wire of the charg'd phial to the rod, instead of the usual stream that I expected from the wire to the rod, there was no spark; not even when I brought the wire and the rod to touch; yet the bells continued ringing vigorously, which proved to me, that the rod was then positively electrify'd, as well as the wire of the phial, and equally so; and, consequently, that the particular cloud then over the rod, was in the same positive state. This was near the end of the gust.

"But this was a single experiment, which, however, destroys my first too general conclusion, and reduces me to this: *That the clouds of a thunder-gust are most commonly in a negative state of electricity, but sometimes in a positive state.*

"The latter I believe is rare; for tho' I soon after the last experiment, set out on a journey to Boston, and was from home most part of the summer, which prevented my making farther trials and observations; yet Mr. Kinnersley returning from the islands just as I left home, pursued the experiments during my absence, and informs me that he always found the clouds in the negative state.

"So that, for the most part, in thunder-strokes, *'tis the earth that strikes into the clouds and not the clouds that strike into the earth.*"

The above quotation is of such a nature as to need no comment. Quite early in his electrical investigations, Franklin

proposed a theory as to the cause of the aurora borealis. The aurora, the "morning hour," takes its name, as is well known, from the fact that the light, seen near the horizon at the beginning of the phenomena, presents an appearance not unlike that of the dawn of day. During the prevalence of the aurora, an arch or corona, as it is called, is to be seen in the northern sky, with its highest part situated immediately under that part which is occupied by the north magnetic pole of the earth. The height of this arch varies in different latitudes, being higher in the higher latitudes than it is in the regions near the Equator.

As the aurora progresses, the arch or corona rises higher in the sky and streams of light of varying colors, white, red and purplish, and sometimes, though more rarely, of the

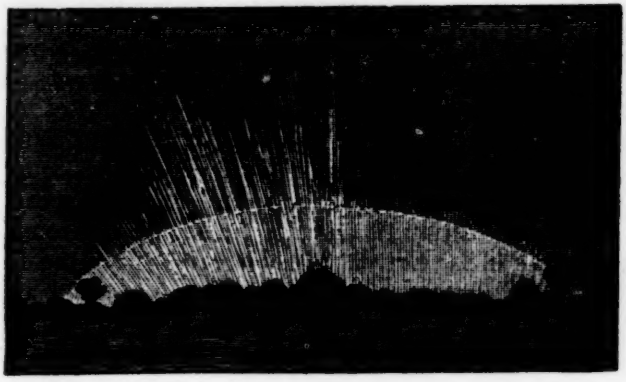


Fig. 8. Aurora Arch (Electricity in Every Day Life—Houston)

other colors of the spectrum, are suddenly to be seen darting in a weird manner upwards from the arch. Sometimes a single streamer will start up, increasing rapidly in size and brilliancy, moving over the sky, and rapidly fading away. At other times, a series of streamers follow one another in rapid succession. The general appearance of the auroral arch is seen in Fig. 8.

As we have already seen, Franklin suggested the cause of the aurora borealis in his history of thunder-gusts. In this paper he calls attention to the fact that the electric fire is never visible unless it is in motion, leaping from body to body, or from particle to particle through the air; that when it is passing in dense bodies it is invisible.

Again, in a letter to Cadwalader Colden, written at Philadel-

phia, April 23, 1752, and read before the Royal Society, November 11th, 1756, he says:

"Your conception of the electrical fluid, that is incomparably more subtile than air, is undoubetdly just. It pervades dense matter with the greatest ease; but it does not seem to mix or incorporate willingly with mere air, as it does with other matter. It will not quit common matter to join with air. Air obstructs, in some degree, its motion. An electric atmosphere cannot be communicated at so great a distance, through intervening air, by far, as through a vacuum. Who knows, then, but there may be, as the ancients thought, a region of this fire above our atmosphere, prevented by our air, and is own too great distance for attraction, from joining our earth? Perhaps where the atmosphere is rarest, this fluid may be densest, and nearer the earth, where the atmosphere grows denser, this fluid may be rarer; yet some of it be low enough to attach itself to our highest clouds, and thence they becoming electrified, may be attracted by, and descend towards the earth, and discharge their watery contents, together with that ethereal fire. Perhaps the aurorae boreales are currents of this fluid in its own region, above our atmosphere, becoming from their motion visible. There is no end of conjectures. As yet we are but novices in this branch of natural knowledge."

Franklin's most complete paper on the aurora borealis was read at the Royal Academy of Sciences, at Paris, at some time immediately before Easter, 1779. It was as follows:

"AURORA BOREALIS.

"Suppositions and Conjectures towards forming an Hypothesis for its Explanation.

"1. Air heated by any means becomes rarefied and specifically lighter than other air in the same situation not heated.

"2. Air being thus made lighter rises, and the neighbouring cooler, heavier air takes its place.

"3. If in the middle of a room you heat the air by a stove, or pot of burning coals near the floor, the heated air will rise to the ceiling, spread there over the cooler air till it comes to the cold walls; there being condensed and made heavier, it descends to supply the place of that cool air which had moved towards the stove or fire, in order to supply the place of the heated air which had ascended from the space around the stove or fire.

"4. Thus there will be a continual circulation of air in the room, which may be rendered visible by making a little smoke; for that smoke will rise and circulate with the air.

"5. A similar operation is performed by nature on the air of the globe. Our atmosphere is of a certain height, perhaps at a medium miles. Above that height it is so rare as to be almost a vacuum. The air heated between the tropics is continually rising, and its place is supplied by northerly and southerly winds which come from those cool regions.

"6. The light, heated air, floating above the cooler and denser, must spread northward and southward, and descend near the two poles, to supply the place of the cooler air which had moved towards the equator.

"7. Thus a circulation of air is kept up in our atmosphere as in the room above mentioned.

"8. That heavier and lighter air may move in currents of different and even opposite directions, appears sometimes by the clouds that happen to be in these currents, as plainly as by the smoke in the experiment above mentioned. Also in opening a door between two chambers, one of which has been warmed, by holding a candle near the top, near the bottom, and near the middle, you will find a strong current of warm air passing out of the warmed room above, and another of cool air entering it below, while in the middle there is little or no motion.

"9. The great quantity of vapor rising between the tropics forms clouds, which contain much electricity.

"Some of them fall in rain, before they come to the polar regions.

"10. If the rain be received in an isolated vessel, the vessel will be electrified; for every drop brings down some electricity with it.

"11. The same is done by snow and hail.

"12. The electricity so descending in temperate climates, is received and imbibed by the earth.

"13. If the clouds are not sufficiently discharged by this means, they sometimes discharge themselves suddenly by striking into the earth, where the earth is fit to receive their electricity.

"14. The earth in temperate and warm climates is generally fit to receive it, being a good conductor.

"15. A certain quantity of heat will make some bodies good conductors, that will not otherwise conduct.

"16. Thus wax rendered fluid, and glass softened by heat, will both of them conduct.

"17. And water, though naturally a good conductor, will not conduct well when frozen into ice by a common degree of cold; not at all where the cold is extreme.

"18. Snow falling upon frozen ground has been found to retain its electricity; and to communicate it to an isolated body, when after falling, it has been driven about by the wind.

"19. The humidity, contained in all the equatorial clouds that reach the polar regions, must there be condensed and fall in snow.

"20. The great cake of ice that continually covers those regions may be too hard frozen to permit the electricity, descending with that snow, to enter the earth.

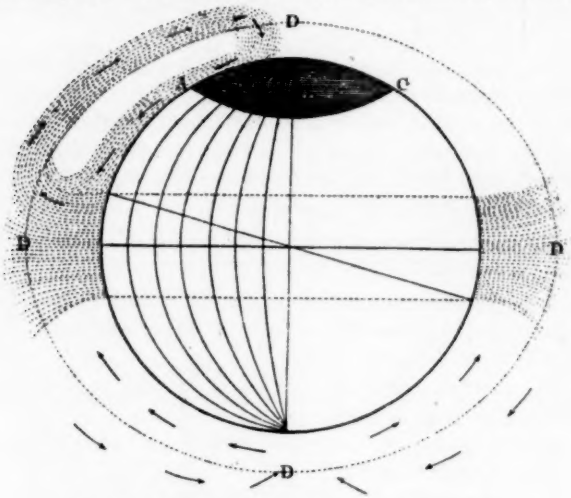
"21. It will therefore be *accumulated upon that ice.*

"22. The atmosphere being heavier in the polar regions, than in the equatorial, will there be lower; as well from that cause, as from the smaller

effect of the centrifugal force; consequently the distance to the vacuum above the atmosphere will be less at the poles than elsewhere; and probably much less than the distance (upon the surface of the globe) extending from the pole to those latitudes in which the earth is so thawed as to receive and imbibe electricity; the frost continuing to latitude 80, which is 10 degrees or 600 miles from the pole, while the height of the atmosphere there, of such density as to obstruct the motion of the electric fluid, can scarce be estimated above miles.

"23. The vacuum above is a good conductor.

"24. May not then the great quantity of electricity brought into the polar regions by the clouds, which are condensed there, and fall in snow,



The Arrows represent the general Currents of the Air.
A.B.C. *the great Cake of Ice & Snow in the Polar Regions.*
D.D.D.D. *the Medium Height of the Atmosphere.*
The Representation is made only for one Quarter and one Meridian of the Globe: but is to be understood the same for all the rest.

Fig. 9. Franklin on the aurora borealis.

which electricity would enter the earth, but cannot penetrate the ice; may it not, I say *(as a bottle overcharged)* break through that low atmosphere and run along in the vacuum over the air towards the equator, diverging as the degrees of longitude enlarge, strongly visible where densest, and becoming less visible as it more diverges; till it finds a passage to the earth in more temperate climates, or is mingled with their upper air?

"25. If such an operation of nature were really performed, would it not give all the appearances of an aurora borealis? See (Plate XI. Fig. 1) Fig C. (Our Figure 9.)

"26. And would not the aurorae become more frequent *after the approach of winter*: not only because more visible in longer nights; but also because in summer the long presence of the sun may soften the surface of the great ice cake, and render it a conductor, by which the accumlation of electricity in the polar regions will be prevented?

"27. The *atmosphere of the polar regions* being made more dense by the extreme cold, and all the moisture in that air being frozen, may not any great light arising therein, and passing through it, render its density in some degree visible during the night-time, to those who live in the rarer air of more southern latitudes? And would it not, in that case, although in itself a complete and full circle, extending perhaps ten degrees from the pole, appear to spectators so placed (who could see only a part of it) *in the form of a segment*, its chord resting on the horizon, and its arch elevated more or less above it, as seen from latitudes more or less distant, *darkish in color*, yet sufficiently *transparent* to permit some stars to be seen through it?

"28. The rays of electric matter issuing out of a body, diverge by mutually repelling each other, unless there be some conducting body near to receive them; and if that conducting body be at a greater distance, they will *first diverge*, and then *converge*, in order to enter it. May not this account for some of the varieties of figures seen at times in the motions of the luminous matter of the aurorae; since it is possible, that, in passing over the atmosphere from the north, in all directions or meridians, towards the equator, the rays of that matter may find, in many places portions of cloudy region, or moist atmosphere under them, which (being in the natural or negative state) may be fit to receive them, and towards which they may therefore converge; and when one of those receiving bodies is more than saturated, they may *again* diverge from it, towards other surrounding masses of such humid atmosphere, and thus form the *crowns*, as they are called, and other figures, mentioned in the histories of this meteor?

"29. If it be true, that the clouds which go to the polar regions carry thither the vapors of the equatorial and temperate regions, which vapors are condensed by the extreme cold of the polar regions, and fall in snow or hail; the winds which come from those regions ought to be generally dry, unless they gain some humidity by sweeping the ocean in their way; and, if I mistake not, the winds between the northwest and northeast are for the most part dry, when they have continued some time."

Considering the early date at which this paper must have been written, it shows the wonderful insight that Franklin had into the causes of the aurora borealis. Note the following points to which he calls attention:

(1) That at a certain height above the level of the sea, the earth's atmosphere is so rare as to be practically a vacuum, and, therefore, a conductor of electricity.

2. That a circulatory movement takes place in the earth's atmosphere between the equator and the polar regions, the lighter air rising and spreading over the colder and heavier air.

(3) That the vapors rising in the tropical regions contain a great quantity of electricity.

(4) That the electricity brought into the polar regions by the vapors as they are condensed is unable readily to reach the earth, by reason of the non-conducting coating of ice and snow that exists in those regions, and therefore "Break through that low atmosphere and run along in the vacuum over the air towards the Equator, diverging as the degrees of longitude enlarge, strongly visible where densest, and becoming less visible as it more diverges, till it finds a passage to the earth in more temperate climate, or is mingled with the upper air."

"If such an operation of nature were really performed, would it not give all appearance of an aurora borealis?"

(5) That the greater frequency of auroras at the approach of winter is due both to the greater length of the nights, in which such phenomena are visible, as well as to the greater extent and thickness of the ice sheet.

(6) That the movements of the luminous matter of the aurora are probably due to the mutual repulsions of the streams of electrified particles.

The general principles contained in Franklin's paper as regards the cause of aurora borealis agree fairly well with somewhat later and more modern views. Consider, for example, the views of the French philosopher De la Rive, as to the cause of the aurora borealis, that he expresses in a paper published in the Philosophical Magazine:

"We have seen that the atmosphere is constantly charged with positive electricity. * * * electricity furnished from the vapors that rise from the sea, essentially in tropical regions, and that, on the other hand, the earth is negatively electrized; the recomposition or neutralization of the two contrary electricities of the atmosphere and of the terrestrial globe is brought about by means of the greater or less moisture with which the lower strata of the air are impregnated. But it is especially in the polar regions, where the eternal ices, that reign there constantly, condense the aqueous vapors under the form of haze, that this recomposition must be brought about; the more so as the positive vapors are carried thither and accumulated by the tropical current, which, setting out from the equatorial

regions, where it occupies the most elevated regions of the atmosphere, descends in proportion as it advances toward the higher latitudes, until in the neighborhood of the poles, where it comes into contact with the earth. It is there then that the discharge between the positive electricity of the vapors and the negative electricity of the earth must essentially take place, with accompaniment of light, when it is sufficiently intense; if, as is almost always the case near the poles, and sometimes in the higher parts of the atmosphere, it meets on its route with extremely small icy particles, which constitute the hazes and the very elevated clouds."

* * * * * * *

"Now, if we examine what ought to take place in the portion of the luminous haze, which is nearest to the terrestial globe, and consequently to the polar regions, we shall find that the magnetic pole should exercise over this electrized matter, which is a veritable movable conductor, traversed by a succession of discharges, an action analogous to that which is exercised in the experiment that we have described when engaged with the luminous effects of electricity, by the pole of an electro-magnet over the jets of electric light that are made to converge in extremely rarefied air. We have seen that, as soon as the soft iron cylinder, which serves as an electro-magnet, is magnetized, the electric light, instead of coming out indifferently from the divers points of the upper surface, that serve as a pole, as had taken place before the magnetization, comes out only from all the points of the circumference of this surface, so as to form around it as it were a continuous luminous ring. This ring possesses a movement of rotation around the magnetized cylinder, sometimes in one direction, sometimes in another, according to the direction of the discharge and the direction of the magnetization. Finally some more brilliant jets seem to come out from this luminous circumference, without being confounded with the rest of the group."

Another of Franklin's contributions to geographical physics, partly electrical in character, was his theory or hypothesis concerning the origin of waterspouts. Waterspouts are phenomena that occur during the progress of a tornado, or, whirling progressive motion of the wind over the ocean. During this movement a funnel-shaped mass of cloud appears over the surface of the ocean. The upper part of the cloud consists of an inverted cone, the base of which rests in the cloud. As the phenomenon progresses, a mass of clouds is projected downward from the lower part of the funnel-shaped mass, and at the same time a column of spray is frequently formed from the ocean, the two uniting in the form of a double inverted cone. The waterspout is due to the rarefaction of the air that is produced by the centrifugal force which drives some of the air from the center of the rotating column, the motion of which is spir-

ally inward and upward. As soon as the moisture laden air enters this central region, where the air pressure is reduced, the temperature of the air is lowered below its dew point, and the vapor is condensed into a cloud. The distance to which water is sucked up from the surface of the ocean is not very high, most of the spout being due to the moisture condensed from the cooler air.

In a paper read June 3, 1756, before the Royal Society, Franklin thus refers to the waterspouts:

(a) "When the air descends with violence in some places, it may rise with equal violence in others, and form both kinds of whirlwinds.

"When air in its whirling motion receding every way from the center or axis of the trumpet, leaves there a vacuum; which cannot be filled through the sides, the whirling air, as an arch, preventing; it must then press in at the open ends.

"The greatest pressure inwards must be at the lower end, the greatest weight of the surrounding atmosphere being there. The air entering, rises within, and carries up dust, leaves, and even heavier bodies that happen in its way, as the eddy, or whirl, passes over land.

"If it passes over water, the weight of the surrounding atmosphere forces up the water into the vacuity, part of which, by degrees, joins with the whirling air, and adding weight, and receiving accelerated motion, recedes still farther from the center or axis of the trump, as the pressure lessens; and at least, as the trump widens, is broken into small particles, and so united with air as to be supported by it, and become black clouds at the top of the trump.

"Thus these eddies may be whirlwinds at land, waterspouts at sea. A body of water so raised may be suddenly let fall, when the motion, &c., has not strength to support it, or the whirling arch is broken so as to let in the air; falling in the sea, it is harmless, unless ships happen under it. But if in the progressive motion of the whirl, it has moved from the sea, over the land, and there breaks, sudden, violent, and mischievous torrents are the consequences."

(a) An excellent statement of the effect produced by a rapid whirling motion of the atmosphere; *i. e.*, the formation of a vacuum at the center of the axis of the whirl, the air only being able to enter at the open ends. Owing to the greater pressure at the bottom than at the top, the maximum pressure inwards is at the bottom, so that the entering air rises, carrying up such readily movable objects as dust, leaves, etc.; and, when passing over the land, and the velocity of the whirl is great, even heavier bodies, thus producing the phenomena of the

whirlwind. As soon, however, as the rotating wind passes over a body of water, the pressure forces the water to enter the empty space at the bottom, most of this water acquiring a rotating motion, the velocity of the whirl increases, thus widening the diameter of the axis. This water, becoming broken into small particles, joins the black clouds at the upper portion of the spout.

In a letter to Dr. ——, of Boston, dated Philadelphia, February 4th, 1753, he gives the following description as to the cause of waterspouts, which is remarkably complete considering the date:

"I ought to have written to you, long since in answer to yours of October 16, concerning the water-spout; but business partly, and partly a desire of procuring further information, by enquiry among my sea-fearing acquaintance, induced me to postpone writing, from time to time, till I am now almost ashamed to resume the subject, not knowing but you may have forgot what has been said upon it.

(a) "Nothing, certainly, can be more improving to a searcher into nature, than objections judiciously made to his opinion, taken up, perhaps, too hastily. For such objections oblige him to re-study the point, consider every circumstance carefully, compare facts, make experiments, weigh arguments, and be slow in drawing conclusions. And hence a sure advantage results; for he either confirms a truth, before too slightly supported; or discovers an error, and receives instruction from the objector.

(b) "In this view I consider the objections and remarks you sent me, and thank you for them sincerely: But, how much soever my inclinations lead me to Philosophical inquiries, I am so engaged in business, public and private, that those more pleasing pursuits are frequently interrupted, and the chain of thought, necessary to be closely continued in such disquisitions, so broken and disjointed, that it is with difficulty I satisfy myself in any of them: And I am now not much nearer a conclusion, in this matter of the spout, than when I first read your letter.

"Yet, hoping we may, in time, sift out the truth between us, I will send you may present thoughts, with some observations on your reasons, on the accounts in the *Transactions*, and on other relations I have met with. Perhaps, while I am writing, some new light may strike me, for I shall now be obliged to consider the subject with a little more attention.

(c) "I agree with you, that, by means of a vacuum in a whirlwind, water cannot be supposed to rise in large masses to the region of the clouds; for the pressure of the surrounding atmosphere could not force it up in a continued body, or column, to a much greater height than thirty feet. But, if there really is a vacuum in the center, or near the axis of whirlwinds, then, I think, water may rise in such vacuum to that height, or to less height, as the vacuum may be less perfect.

"I had not read *Stuart's* account, in the *Transactions*, for many years, before the receipt of your letter, and had quite forgot it; but now, on viewing his draughts, and considering his descriptions, I think they seem to favour *my hypothesis*; for he describes and draws columns of water, of various heights, terminating abruptly at the top, exactly as water would do, when forced up by the pressure of the atmosphere into an exhausted tube.

(d) "I must, however, no longer call it *my hypothesis*, Since I find *Stuart* had the same thought, though somewhat obscurely expressed, where he says 'he imagines this phaenomenon may be solv'd by suction (improperly 'so called) or rather pulsion, as in the application of a cupping glass to the 'flesh, the air first voided by the kindled flax.'

(e) "In my paper, I supposed a whirlwind and a spout to be the same thing, and to proceed from the same cause; the only difference between them being, that the one passes over land, the other over water. I find, also, in the *Transactions*, that *M. de la Pryme* was of the same opinion; for he there describes two spouts, as he calls them, which were seen at different times, at *Hatfield* in *Yorkshire*, whose appearances in the air were the same with those of the spouts at sea, and effects the same with those of real whirlwinds.

'Whirlwinds have, generally, a progressive, as well as a circular motion; so had what is called the spout, at *Topsham* * * * *(See the account of it in the Transactions)*, which also appears, by its effects described, to have been a real whirlwind. Water-spouts have, also, a progressive motion; this is sometimes greater, and sometimes less; in some violent, in others barely perceivable. The whirlwind at *Warrington* continued long in *Acrement-Close*.

"Whirlwinds generally arise after calms and great heats: The same is observed of water-spouts, which are, therefore, most frequent in the warm latitudes. The spout that happened in cold weather, in the *Downs*, described by *Mr. Gordon* in the *Transactions*, was, for that reason, thought extraordinary; but he remarks withal, that the weather, though cold when the spout appeared, was soon after much colder; as we find it, commonly, less warm after a whirlwind.

"You agree, that the wind blows every way towards a whirlwind, from a large space round. An intelligent whaleman of Nantucket, informed me, that three of their vessels, which were out in search of whales, happening to be becalmed, lay in sight of each other, at about a league distance, if I remember right, nearly forming a triangle: After some time, a water-spout appeared near the middle of the triangle, when a brisk breeze of wind sprung up, and every vessel made sail; and then it appeared to them all, by the setting of the sails, and the course each vessel stood, that the spout was to the leeward of every one of them; and they all declared it to have been so, when they happened afterwards in company, and came to confer about it. So that in this particular likewise, whirlwinds and water spouts agree.

"But, if that which appears a water-spout at sea, does sometimes, in its progressive motion, meet with and pass over land, and there produce all

the phaenomena and effects of the whirlwind, it should thence seem still more evident that the whirlwind and a spout are the same. I send you, herewith, a letter from an ingenious physician of my acquaintance, which gives one instance of this, that fell within his observation.

"A fluid, moving from all points horizontally, towards a center, must, at that center, either ascend or descend. Water being in a tub, if a hole be opened in the middle of the bottom, will flow from all sides to the center, and there descend in a whirl. But, air flowing on and near the surface of land or water, from all sides, towards a center, must, at that center, ascend; the land or water hindering its descent.

"If these concentring currents of air be in the upper region, they may, indeed, descend in the spout or whirlwind; but then, when the united current reached the earth or water, it would spread, and, probably, blow every way from the center. There may be whirlwinds of both kinds, but, from the commonly observed effects, I suspect the rising one to be the most common: When the upper air descends, it is, perhaps, in a greater body, extending wider, as in our thunder-gusts, and without much whirling; and, when air descends in a spout, or whirlwind, I should rather expect it would press the roof of a house *inwards*, or force *in* the tiles, shingles, or thatch; force a boat down into the water, or a piece of timber into the earth, than that it would lift them up, and carry them away.

"It has so happened, that I have not met with any accounts of spouts, that certainly descended; I suspect they are not frequent. Please to communicate those you mention. The apparent dropping of a pipe from the clouds towards the earth or sea, I will endeavor to explain hereafter.

"The augmentation of the cloud, which as I am informed, is generally, if not always the case, during a spout, seems to shew an ascent, rather than a descent of the matter of which such cloud is composed; for a descending spout, one would expect, should diminish a cloud. I own, however, that cold air descending, may, by condensing the vapours in a lower region, form and increase clouds; which I think, is generally the case in our common thunder-gusts, and, therefore, do not lay great stress on this argument.

"Whirlwinds, and spouts, are not always, though most commonly, in the day time. The terrible whirlwind which damaged a great part of Rome, June 11, 1749, happened in the night of that day. The same was supposed to have been first a spout, for it is said to be beyond doubt, that it gathered in the neighbouring sea, as it could be tracked from *Ostia* to *Rome*. I find this in *Pere Boschovich's* account of it, as abridg'd in the *Monthly Review* for December, 1750.

"In that account, the whirlwind is said to have appeared as a very black, long, and lofty cloud, discoverable, notwithstanding the darkness of the night, by its continually lightning or emitting flashes on all sides, pushing along with a surprising swiftness, and within three or four feet of the ground. Its general effects on houses, were, stripping off the roofs, blowing away chimneys, breaking doors and windows, *forcing up the floors and unpaving the rooms*, (some of these effects seem to agree well with a supposed vacuum in the center of the whirlwind) and the very rafters of the houses

were broke and dispersed, and even hurled against houses at a considerable distance, &c.

"It seems, by an expression of *Pere Boschovich's*, as if the wind blew from all sides towards the whirlwind; for, having carefully observed its effects, he concludes of all whirlwinds, 'that their motion is circular, and their action attractive.'

"He observes, on a number of histories of whirlwinds, &c., 'that a com-'mon effect of them is, to carry up into the air tiles, stones, and animals 'themselves, which happen to be in their course, and all kinds of bodies un-'exceptionably, throwing them to a considerable distance, with great im-'petuosity.' Such effects seem to shew a rising current of air.

(f) "I will endeavor to explain my conception of this matter by figures, representing a plan and an elevation of a spout or whirlwind.

"I would only first beg to be allowed two or three positions, mentioned in my former paper.

"1. That the lower region of air is often more heated, and so more rarified, than the upper; consequently, specifically lighter. The coldness of the upper region is manifested by the hail which sometimes falls from it on a hot day.

"2. That heated air may be very moist, and yet the moisture so equally diffus'd and rarified, as not to be visible, till colder air mixes with it, when it condenses, and becomes visible. Thus our breath, invisible in summer, becomes visible in winter.

"Now, let us suppose a tract of land, or sea, of perhaps sixty miles square, unscreened by clouds, and unfanned by winds, during great part of a summer's day, or, it may be, for several days successively, till it is violently heated, together with the lower region of air in contact with it, so that the said lower air becomes specifically lighter than the superincumbent higher region of the atmosphere, in which the clouds commonly float: Let us suppose, also, that the air surrounding this tract has not been so much heated during those days, and, therefore, remains heavier. The consequence of this should be, as I conceive, that the heated lighter air, being pressed on all sides, must ascend, and the heavier descend; and, as this rising cannot be in all parts, or the whole area of the tract at once, for that would leave too extensive a vacuum, the rising will begin precisely in that column that happened to be the lightest, or most rarified; and the warm air will flow horizontally from all points to this column, where the several currents meeting, and joining to rise, a whirl is naturally formed, in the same manner as a whirl is formed in the tub of water, by the descending fluid flowing from all sides of the tub, to the hole in the center.

"And, as the several currents arrive at this central rising column, with a considerable degree of horizontal motion, they cannot suddenly change it to a vertical motion; therefore, as they gradually, in approaching the whirl, decline from right to curve or circular lines, so, having joined the whirl, they *ascend* by a spiral motion; in the same manner as the water *descends* spirally through the hole in the tub before-mentioned.

"Lastly, as the lower air, and nearest the surface, is most rarified by the heat of the sun, that air is most acted on by the pressure of the surrounding cold and heavy air, which is to take its place; consequently, its motion towards the whirl is swiftest, and so the force of the lower part of the whirl, or trump, strongest, and the centrifugal force of its particles greatest; and hence the vacuum round the axis of the whirl should be greatest

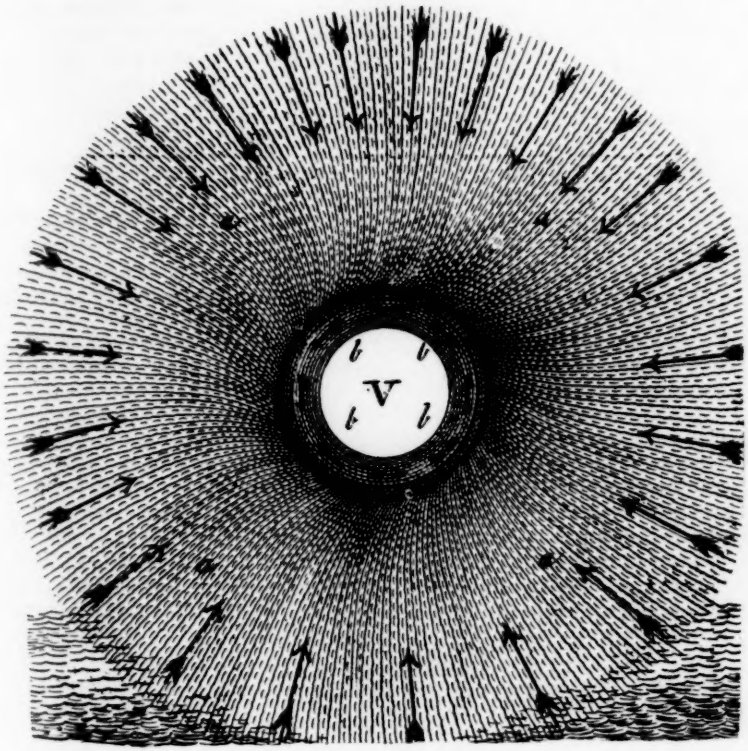


Fig. 10. Plan of Water Spout. (Franklin)

near the earth or sea, and be gradually diminished as it approaches the region of the clouds, till it ends in a point, as at A, in Fig. II, forming a long and sharp cone.

(g) "In Fig. I (D) which is a plan or ground-plat of a whirlwind, the circle V represents the central vacuum. (Our figure 10.)

"Between *a a a a* and *b b b b* I suppose a body of air condensed strongly by the pressure of the currents moving towards it, from all sides without, and by its centrifugal force from within; moving round with prodigious swiftness, (having, as it were, the momenta of all

the current united in itself) and with a power equal to its swiftness and density.

"It is this whirling body of air between *a a a a* and *b b b b* that rises spirally; by its force it tears buildings to pieces, twists up great trees by the roots, &c., and, by its spiral motion, raises the fragments so high, till the pressure of the surrounding and approaching currents diminishing, can no longer confine them to the circle; or their own centrifugal force increasing, grows too strong for such pressure, when they fly off in tangent lines, as stones out of a sling, and fall on all sides, and at great distances.

"If it happens at sea, the water under and beneath *a a a a* and *b b b b* will be violently agitated and driven about, and parts of it raised with the spiral current, and thrown about, so as to form a bushlike appearance.

"This circle is of various diameters, sometimes very large.

"If the vacuum passes over water, the water may rise in it in a body, or column, to near the height of thirty-two feet.

"If it passes over houses, it may burst their windows or walls outwards, pluck off the roofs, and pluck up the floors, by the sudden rarefaction of the air contained within such buildings; the outward pressure of the atmosphere being suddenly taken off: So the stopp'd bottle of air bursts under the exhausted receiver of the air-pump.

(*To be continued.*)

LEAD IN BRONZE BEARING METALS.

Bronzes containing lead are much used for bearings. The lead does not alloy directly with the bronze, but remains in separate particles, which are seen under the microscope. The lead increases the plasticity of the alloy to a marked degree. There is a tendency to the separation of the lead by liquidation, as it has a much lower solidifying point than the bronze. Even if the metal is not poured until it has acquired a pasty consistency, there is a tendency for the heavy particles to sink in the mass. It is difficult to be assured of an equal distribution of the metals in such alloys, and the exact composition at the rubbing surface is unknown.—ENGINEERING AND MINING JOURNAL.

CONCRETE BLOCKS IN BUILDING.

The prizes offered by *Engineering News* and the *Cement Age* of New York for the best papers on "The Manufacture of Concrete Blocks and Their Use in Building Construction" have just been awarded by the jury, which was composed of Robert W. Lesley, past president of the American Cement Manufacturers' Association; Richard L. Humphrey, president of the Cement Users' Association and Prof. Edgar Marburg, secretary of the American Society for Testing Materials. The first prize of $250 was won by H. H. Rice, Denver, Col., secretary of the American Hydraulic Stone Company. The second prize of $100 was given to Wm. M. Torrance, New York City, assistant engineer in charge of concrete steel design for the Hudson Tunnel companies.

TALBOT CONTINUOUS OPEN-HEARTH PROCESS INSTALLATIONS.

It is now estimated that the steel producing capacity employing the Talbot process amounts to nearly 1,000,000 tons a year in the United States and Great Britain. The installations now in operation or under construction are as follows:

One 75-ton furnace, built in 1899 by the Pensoyd Iron Company, Pencoyd, Pa. Now in operation.

One 200-ton furnace, built in 1902 by Jones & Laughlin Steel Company, Pittsburgh, Pa. Now in operation.

One 200-ton furnace, built in 1904 by Jones & Laughlin Steel Company, Pittsburgh, Pa. Now in operation.

Three 200-ton furnaces, built in 1905 by Jones & Laughlin Steel Company, Pittsburgh, Pa. Now in operation.

One 100-ton furnace, built in 1902 by Frodingham Iron Company, Frod-

One 130-ton furnace, built in 1905 by Frodingham Iron Company, Frodingham, England. Now in operation.

ingham, England. Now in operation.

One 175-ton furnace, built in 1903 by Guest, Keen & Company, Cardiff, South Wales. Now in operation.

Two 175-ton furnaces, built in 1905 by the Cargo Fleet Iron Company, Limited, Middlesboro, England. Now in operation.

One 75-ton furnace under construction by the Cargo Fleet Iron Company, Limited, Middlesboro, England.

Two 175-ton furnaces under construction by the South Durham Steel & Iron Company, Limited, Middlesboro, England.

Two 175-ton furnaces under construction at the Malleable Works, Stockton-on-Tees, England.

Two 175-ton furnaces under construction by the Palmer Shipbuilding Company, Jarrow-on-Tyne, England.

Two 175-ton furnaces under construction at Longwy, France.

It is expected that the producing capacity under the Talbot process will be increased materially in 1906.—*Iron Age.*

EXPLOSION OF RADIUM TUBES.

In the issue of *Physikalische Zeitschrift* for January 15, 1906, Mr. J. Precht describes some experiences with radium which tend to show the enormous force of the ommitted gaseous products when they are confined to a limited space. He reports that a small glass tube with walls 0.5 mm. thick, containing 25 milligrammes of purest radium bromide, exploded after 11 months' use with a loud report. Three minutes before the explosion it had been removed from a bath of liquid air and placed on a wooden table. It had been used several times before. The force of the explosion was such that the glass was shivered into almost microscopic particles which were strewn all over the room, the radium being seen in the dark like a starry sky. The pressue in the tube must have been at least 20 atmospheres, and was no doubt due to the evolution of gaseous decomposition proucts of radium.

ALUMINOSILICIDES.

According to E. Vigouroux *(Comptesrend.*, 1905, CXLI, 951-953), pure silicon and aluminum, whether fused together, or whether the silicon be formed from silica by the thermite process in presence of excess of aluminum, refuse to combine, but when they are in presence of a third metal, double silicides of aluminum and the metal, or aluminosilicides of the metal, are formed. These are definite, crystaline substances, with metallic luster, dense, hard and brittle; some are attacked by dilute acids, but most of them resist all acids, even when concentrated, save hydrofluoric acid, and none of them is affected by solutions of alkali. They are formed by heating the three elements together in an atmosphere of hydrogen, or by the thermite method from mixtures of silica and a metallic oxide, using excess of aluminum, or by acting with aluminum on a mixture of the metal or its oxide or sulphide with potassium silicofluoride. In view of these facts, clay vessels should be avoided in the preparation of metals which can form aluminosilicides.

THE BATTLESHIP DREADNOUGHT, which will cost completed $7,500,000, was launched by King Edward at Portsmouth, Eng., February 10. On October 2, 1905, work was begun on the vessel, and it is expected that the Dreadnought will be commissioned at the end of another year, making a record six months less than the shortest time in which a battleship has been built. The tonnage of the Dreadnought will be 18,000, the length exceeding 500 feet and the beam 80 feet. Turbine engines are provided, with 23,000 horse-power, and the guaranteed speed is 21 knots. Armor plates are 12 inches thick, extending almost the entire length and 7 feet below the water line. The armament will consist of ten 12-inch guns in five turrets. No previous warship has carried more than four 12-inch guns.

PRODUCTION OF ALUMINUM IN EUROPE.

The output of aluminum by the Pittsburg Reducing Company in Canada and the United States is placed at 4,200 tons. The high grade of copper has recently developed new interest in the production of the metal, whose price has risen in spite of the growing quantity available, and which has come into large demand in the electric field. United States Consul Guenther, of Frankfort, sends the following German report on the European situation:

"The companies at present producing aluminum are: 1. Aluminium Industrie A. G., in Neuhausen, Switzerland, which also has works at Lend-Gastein, Austria, and at Rheinfelden. Baden. The total annual production of the three works of this company was estimated at 3,675 tons (at 2,204 metric pounds), employing 88 bureau officials and 661 workmen. It paid last year on its stock an 18 per cent. dividend, and recently raised its share capital from 16 to 26 million francs. The new shares were taken by a bankers' syndicate at 250 per cent."

AMERICAN LOCOMOTIVES EXCEL.

The superiority of American passenger locomotives over those of the best foreign build as regards speed, economy and power is shown in results of exhaustive tests made under the supervision of some of the leading American and European engineers, just made public.

The work was begun by the Pennsylvania Railroad Company at the St. Louis Exposition and covered a period of more than six months. The tests were most elaborate and involved an expenditure of $250,000.

The tests were made under the direction of an Advisory Committee, consisting of three members each of the American Society of Mechanical Engineers and of the American Railway Master Mechanics' Association. These were Dr. W. F. M. Goss, dean of the Schools of Engineering, Purdue University; Edwin M. Herr, vice-president of the Westinghouse Electric and Manufacturing Company: E. Sague, first vice-president of the American Locomotive Company; F. H. Clark, general superintendent of motive power of the Chicago, Burlington and Quincy Railroad; C. H. Quereau, superintendent of electrical equipment of the New York Central and H. H. Vaughan, superintendent of the motive power of the Canadian Pacific Railway. The affiliated members of the committee included John A. F. Aspinall, general manager of the Lancaster and Yorkshire Railway of England, and Karl Steinbiss, director of the Royal Prussian Railway, Germany.

The American passenger engines tested were one of the New York Central high speed type used for hauling the Empire State Express and one of the Atchinson, Topeka & Santa Fe Road's balanced compound. Several freight engines were also submitted to test.

One of the foreign locomotives was the much-heralded de Glehn balanced compound, built by the Société Alsacienne de Constructions Mecaniques at Belfort, France. This type of locomotive is used on the Chemins de Fer de Nord, between Calais and Paris, and makes one of the fastest runs in the world. It is also in use on the Great Western Railway of England. This engine is regarded by European experts as the acme of high speed passenger service perfection on the other side. The other European locomotive tested came from the Hannoversche Machinenbau-Actien-Gesellschaft, Linden Vor Hannaver, Germany. This engine was built for the directors of the Royal Prussian Railway Administration.—Iron Age.

COMPARATIVE ECONOMY OF STEAM AND TURBINE ENGINES.

A saving in coal of about 9 er cent., at a speed of between 19 and 20 knots, was computed for the turbine steamers belonging to the Midland Railway (England), as compared with similar steamers of the same company propelled by reciprocating engines. The principal inferiority of the turbine vessels seems to have consisted in a difficulty in maneuvring in narrow channels, which difficulty it is believed may be readily overcome by the expedient of putting more power into the turbines used for backing. The difference in weight of machinery and in initial cost was found to favor the turbine driven ships by margins of 6 and 1½ per cent., respectively.

BARYTES MINING IN VIRGINIA.

In connection with some of the barytes deposits of Virginia, the mining problem is very simple. In fact the problem is not one of mining, but rather of handling the material by industrial railways and other similar appliances. However, the deposits are so scattered and so small that it makes the problem rather difficult, inasmuch as the proper appliance to handle the dirt and ore to the best advantage would clean out some deposits in a few weeks.

The best and most available barytes occurs in a sort of loamy dirt. An ideal way to handle this would be to put in a steam shovel and log washer somewhat as brown ore is handled in the South, but as a thousand tons of barytes from one lease is an exceptionally large amount, it would be impractical to instal such a plant. The usual method is to make an open cut, follow the barytes where it leads and reject the dirt. Below the dirt the barytes runs into the limestone, and if that is in such a place that cheap transportation is available it pays to work.

In some places, far from the railroad, the cost of teaming is greater than the cost of mining. The limestone deposits might be worked more easily by the use of jigs. The uncertainty of the business, however, has prevented such innovations. In the Virginia district it is rather hard to accumulate sufficient barytes to run a good sized mill. The soft nature of the barytes is rather against mechanical handling, and even if there were a sufficient amount to warrant putting in a steam shovel and washer, the waste might be too great. The best and most abundant deposits seem to be the farthest from the railroad. If they were all contracted at one point, barytes mines would be a good proposition.—ENGINEERING AND MINING JOURNAL.

HARDENING STEEL.

R. A. Hadfield, Sheffield, Eng., has been granted a patent in the United States on a process of hardening steel. The first claim is on a method of hardening steel which consists in raising the temperature of the steel to about 975° centigrade, permitting it to cool slowly, reheating the cooled steel to a temperature of about 500° centigrade and permitting the steel to cool slowly after such reheating. The remaining claims introduce variations in the above temperatures, the heat employed varying according to the amount of carbon in the steel.

TESTS HAVE BEEN MADE recently on the corrosion of boiler-tubes by forcing air through tubes made wet with distilled water. In 16 weeks the loss in weight was .315 gram per sq. in. When the water was made alkaline the loss in the same time was reduced to only .0997 gram. It apears that if the water in the boiler is made slightly alkaline the corrosion of tubes may be materially reduced.—(London) NATURE.